CALIFORNIA
DEPARTMENT OF
CONSERVATION
Division of Mines and Geology

SPECIAL PUBLIC

PHYSICAL SCIENCES
LIBRARY
UC DAVIS

SEISMIC HAZARD INFORMATION NEEDS of the INSURANCE INDUSTRY, LOCAL GOVERNMENT, and PROPERTY OWNERS in CALIFORNIA

AN ANALYSIS

1990

UNIVERSITY OF CALIFORNIA
DAVIS
OCT 30 1991
GOV'T. DOCS. - LIBRARY

THE RESOURCES AGENCY
Gordon K. Van Vleck
Secretary for Resources

STATE OF CALIFORNIA
George Deukmejian
Governor

DEPARTMENT OF CONSERVATION
Randall M. Ward
Director

DIVISION OF MINES AND GEOLOGY
JAMES F. DAVIS
STATE GEOLOGIST

Cover: Collapse of a residence in Watsonville during the 1989 Loma Prieta earthquake. Close proximity to the epicenter and soft alluvial sediments resulted in severe ground shaking in the Watsonville area. *Photo by John K. Nakata, U.S. Geological Survey.*

SPECIAL PUBLICATION 108

SEISMIC HAZARD INFORMATION NEEDS of the INSURANCE INDUSTRY, LOCAL GOVERNMENT, and PROPERTY OWNERS in CALIFORNIA

AN ANALYSIS

1990

By

RICHARD HOLDEN
Public Policy Consultant

and

CHARLES R. REAL
Senior Seismologist and Project Manager
Division of Mines and Geology

CALIFORNIA DEPARTMENT OF CONSERVATION
Division of Mines and Geology
1416 Ninth Street, Room 1341
Sacramento, CA 95814

UNIVERSITY OF CALIFORNIA
DAVIS
OCT 04 1991
CALIF. DEPOS.
GOV'T. DOCS. - LIBRARY

Digitized by the Internet Archive
in 2012 with funding from
University of California, Davis Libraries

http://archive.org/details/seismichazardinf108hold

PREFACE

In 1987, the California State Legislature mandated the Department of Insurance and the Department of Conservation to examine critical issues related to the provision of earthquake insurance in California. The Department of Conservation's principal role in the mandate was to design a study to provide improved seismic hazard information to the public, local government, and the insurance industry. It was immediately recognized that such a study would consist of a long-term program, and that the principal objective of the mandate would be to design a program that would be effective in meeting the information needs of those beneficiaries. Consequently, a major effort was directed to defining the needs of the beneficiaries; in essence, the appropriate products of such a program.

Our philosophy was that by careful definition of products and by understanding the process within which they will become a part, and by this we mean addressing the important sociological, economic, and political issues surrounding their use, the remaining tasks would become clearly defined. These remaining tasks would constitute what is necessary to produce effective products, and would result in the design of an effective program.

Earth science technology has developed rapidly, and there are many new tools and methods with which to better understand and communicate seismic hazard and risk. There are many seismic hazard products that have been produced over the years, but most are not meeting the needs of the intended beneficiaries because their development has followed the more traditional path of research-to-product without adequate interaction with the end users. It is hoped that the approach taken in this study, by emphasizing analysis of user needs, will avoid these pitfalls and lead to the design of a viable program that will have a significant impact or seismic hazard mitigation in California.

Charles R. Real
Project Manager

ACKNOWLEDGMENTS

We wish to thank the various public agencies, including planning and building departments and flood control and water districts of the cities and counties we visited for their cooperation. We also wish to thank the geotechnical industry in southern and northern California for its generosity in supplying location information on past projects. Our appreciation is extended to the insurance industry representatives who offered their insights on seismic hazard information needs and methods of exposure analysis used by the industry. We thank the Department of Civil Engineering of Stanford University for enlightening discussions about IRAS, and knowledge-based systems for seismic hazard analysis.

Finally, we wish to thank Mark DeLisle who evaluated adequacy of existing bore-hole data, Michael Reichle who reviewed the manuscript and made several useful suggestions, and Richard Roth, Jr. and Karl Steinbrugge who acted in an advisory capacity throughout the duration of this study.

Edited by Alison Kenward and Lena Tabilio
Graphic design and layout by Peggy Walker

CONTENTS

CONTENTS (Continued)

TABLES

FIGURES

FIGURES (Continued)

Severe damage to an old motel caused by strong ground shaking during the 1983 Coalinga earthquake. Such damage is very typical for unreinforced masonry structures (URM). Recent California law requires local government to prepare an inventory of URM's within their jurisdiction in order to help identify those buildings that are in greatest need of seismic retrofitting. Delineation of seismic hazards zones can help prioritize URM hazard mitigation programs. *Photo by Charles Real.*

EXECUTIVE SUMMARY

The Department of Conservation's Division of Mines and Geology was directed by the Legislature to design a program that will provide improved information on seismic hazards to the public, local government, and the insurance industry. The study involved three principal tasks: 1) an assessment of the information needs of the beneficiaries, 2) identification of the methods and technology required to produce the specific information desired, and 3) evaluation of the adequacy of existing geoscience information needed to produce the products. Our conclusions are summarized as follows:

- Improved seismic hazards information would be used by insurance companies, local governments, and property owners. The data needs of each of these groups are different but could be accommodated within a single program.

- A special study zone approach used to delineate severe ground shaking, liquefaction, and landslide hazards may provide useful information to insurers, local governments, and property owners. Seismic Hazards Studies Zones (SHSZs) would provide local governments with a focused policy instrument for improving safety of development. Disclosure to prospective property purchasers of SHSZs would assist the real estate market in setting more appropriate prices for properties in hazardous areas and support local governments' desire to discourage development in hazardous areas. Finally, the insurers' desire for identifying relative levels of hazard severity would be supported by maps and information which delineate the extreme high-hazard areas.

- A SHSZ program should include the following components: (1) delineating of high-hazard areas, (2) requiring local governments to make SHSZs part of general planning and land suitability determinations, (3) conditioning all development within SHSZs on completion of special site studies which detail the hazard and mitigation, and (4) requiring early disclosure to prospective property purchasers of the existence of SHSZs.

- Other hazard zone measures may be adopted which will enhance the effectiveness of a SHSZ program. These measures include: (1) conditioning future State disaster assistance on adoption of mitigation planning and hazard reduction measures by local government, (2) establishing provisions for assessments or fees in SHSZs, and (3) requiring adoption of reconstruction ordinances.

- General methods are available to delineate, on a statewide basis, the existence of ground shaking, liquefaction, and landslide hazards. There exists a wealth of private and public data which can be cost-effectively employed to support mapping these hazards.

- Delineation of hazards by the State is: (1) consistent with protecting the State's interests, (2) efficiently accomplished by a State level organization, and (3) ensures coordination between jurisdictions.

CHAPTER ONE—INTRODUCTION

Chapter 1112, Statutes of 1987 directed the Department of Insurance and the Department of Conservation, Division of Mines and Geology (DMG), to undertake various activities regarding the issuance of earthquake insurance, geologic hazards investigation, and an assessment of the dollar exposure of insurance companies operating in California. The Division of Mines and Geology was specifically directed to prepare an urban geological hazards mapping study to:

- "improve the information available to property owners, local governments, and to the insurance industry regarding geologic-seismic hazards and on the severity and likelihood of ground shaking and related secondary hazards such as liquefaction and slope failure."

To address this requirement, the DMG initiated several activities to:

- Perform an analysis of the need for improved geologic hazards information by local governments, insurance companies, and property owners,
- Identify methods of assessing earthquake-induced geologic hazards, and
- Assess the adequacy of existing bore-hole data collected by public agencies and geotechnical consultants.

This report presents the findings from these activities, and makes recommendations affecting the design of an Urban Seismic Hazards Mapping Program (USHMP).

INFORMATION NEEDS

This seismic information needs analysis was initiated by issuing a contract for a policy analyst to assist staff in collecting and analyzing information. The policy analyst was requested to: (1) identify specific entities and potential uses of products to reduce future earthquake losses, (2) analyze existing policies and procedures of principal users and make policy recommendations for effective implementation of USHMP products, (3) identify and make recommendations to resolve product development and implementation issues, (4) assess cost-effectiveness, and (5) assist in program development, including a programmatic description, an action plan, budget change proposal, necessary legislation, and identification of funding sources. This report includes the results of the policy analysis work outlined by DMG.

METHODOLOGY

The methodology used to assess uses, values, and policy issues includes:

- Literature review–insurance risk estimation and uses of geologic hazard information by local government and the public.
- Review of seismic safety and safety elements in several local government general plans.
- Review of selected loss estimation methods for insurance.
- A survey of insurance industry officials.
- Interviews with local government personnel.
- Analysis of interviews and survey responses for the type and quality of information requested as well as the congruence of needs between users.

ORGANIZATION

Chapter Two outlines the background problems and issues surrounding the use of geologic hazard information. The chapter discusses earthquake insurance status in California, local government planning and building department functions and seismic safety, and information on public information, disclosure, and emergency preparedness.

Chapter Three details the current and anticipated uses of geologic hazard information by insurance companies and earthquake insurance risk consultants. In addition, this section discusses the results of surveys of insurance companies and informal interviews conducted with industry personnel.

Chapter Four reviews recent research on uses of geohazard information by local governments and property owners. The results of interviews with planners, building officials, and property owner organizations are discussed. In addition, the chapter outlines three exemplary local government programs that translate geohazards information into hazards reduction measures.

Chapter Five discusses the programmatic and policy implications of our data collection activities with insurance companies, local governments, and property owners. Several hazard zone measures suggested by our review of current practices are discussed. The issues of state accountability for hazard reduction, inverse condemnation, potential changes in property values, and adverse selection are discussed. In addition, parameters for deciding on the appropriate level of effort and funding for a seismic hazards studies zone program are provided.

Chapter Six contains a discussion of methods and data requirements for hazard assessment, particularly for Seismic Hazards Studies Zones. This chapter also lists data sources that are available and that can make a hazard zoning program economically feasible. Following Chapter Six is a reference section of materials consulted during the preparation of this report. Finally, a set of appendices provides additional detail and background materials.

Liquefaction during the 1971 San Fernando earthquake caused serious damage to a Los Angeles County Juvenile Hall Facility. Prior knowledge of hazard potential can permit mitigation by site remediation or foundation design. *Photo by Charles Real.*

CHAPTER TWO—BACKGROUND

This chapter outlines the background problems and issues regarding earthquake hazards and the insurance industry, planning and building departments, and various other users or potential users of geological hazards information. The chapter discusses the uses of seismic hazards data in (1) the California earthquake insurance market, (2) local government planning and building department functions, and (3) public information efforts, such as disclosure to prospective property purchasers, and emergency preparedness activities.

EARTHQUAKE INSURANCE PROBLEMS, ISSUES, AND CURRENT STATUS

Damaging earthquakes, like other natural hazards, pose difficult problems for the insurance industry. They occur rarely, unpredictably, and have the potential to inflict calamitous damage. In areas of relatively high seismicity like California, insurers must cope with two types of potential losses: (1) annual losses, which result from smaller but more frequent earthquakes, and (2) catastrophic losses which result from very large, but rare events. Annual loss can be calculated based on the expected occurrence of various size earthquakes over a period of several years or decades. To the extent that there are annual probabilities associated with various earthquakes, insurers are able to assess the potential for annual loss. Errors in estimating annual losses, which, by their nature, are small losses, are unlikely to threaten an insurer.

Catastrophic losses generated by great earthquakes, on the other hand, are likely to threaten the financial solvency of insurers, banks, governments, and other institutions. Also, because catastrophic earthquakes happen so rarely, their annual probabilities are less estimable.

Between 1900 and 1987, 192 earthquakes of magnitude 5.5 or greater occurred within or near California. As shown in Figure 2.1, the number of M5.5-6.5 earthquakes is much greater than the number of M6.6-7.5 or M7.5 and larger earthquakes. The cumulative area subjected to damaging ground motion, however, is greater for larger magnitude earthquakes even though the number of events is much fewer. This result is expected because a unit increase in the magnitude of an earthquake represents a ten-fold increase in shaking amplitude and a thirty-fold increase in energy, causing the area shaken at a given level of severity to increase exponentially (Richter,1958).

In order to represent the cumulative areas affected by various size earthquakes, we calculated the areas that would experience damaging ground motion (Modified Mercalli intensity VII or greater)[1] by each event detected in California, western Nevada, and northern Baja California between 1900 and 1987. The measure of cumulative areas damaged was calculated using an empirical relation between magnitude MMI and VII[2] and represents, in a general way, the area of exposure to damaging earthquakes between 1900 and 1987. Note that these cumulative areas encompass all areas within reach of strong ground motion emanating from an earthquake, including offshore and sparsely populated areas. Thus, these areas tend to *overstate* the areas that would actually experience damage. Nonetheless, they are useful in comparing the relative amounts of damaged areas that are generated by earthquakes of various magnitudes.

In addition to the problems of anticipating annual and catastrophic earthquakes, there is also considerable uncertainty regarding earthquake damage estimation. These uncertainties result from the many variables that must be assessed. There are uncertainties in earthquake fault sources, patterns of shaking, site effects, building damage, fault rupture, effects of collateral hazards (such as liquefaction and landslides), and other loss conditions. As a result of the manifold uncertainties in loss estimation, a company offering earthquake coverage is faced with the intransigent problem of assessing potential losses in order to reserve sufficient funds to pay earthquake coverage claims when an event occurs. In addition, insurance companies must try to anticipate claims to other coverages that directly or indirectly result from an earthquake. Thus, even if a particular earthquake could be accurately predicted as to its location, magnitude, and broad time frame, there would still be considerable uncertainty in loss estimation.

Based on our conversations with industry officials, insurance companies are particularly concerned with the potential for a catastrophic earthquake. Several studies have been completed by the All-Industry Research Advisory Council (AIRAC), an insurance-funded research organization, in an attempt to address the catastrophic potential of a major or great earthquake in California and catastrophic losses, generally. The AIRAC reports provide estimates of earthquake losses under workers' compensation, general liability insurance and

1 See Appendix B for definition of Modified Mercalli Intensity scale.
2 The relation was obtained from regressions performed by Toppozada (1975) on intensity data for California and western Nevada earthquakes occurring between 1950 and 1971, relating magnitude to maximum reported intensity areas. The relation for Modified Mercalli intensity VII levels of damage is given by: Magnitude = 3.49 + .87 Log (Area).

from fire following earthquake. The workers' compensation and general liability assessments published in October 1988 projects that a M7.5 earthquake on the Newport-Inglewood fault would result in insurance payments ranging from $9.5 to $19.7 billion, with the most likely loss estimated at $14.6 billion (Friedman, 1988). The fire following earthquake study estimates that fire losses in the Los Angeles basin for a M6.5 Newport-Inglewood earthquake would range from $13-$17 billion; a M7.5 earthquake could generate approximately $24 billion in fire losses (Scawthorn, 1987). In the San Francisco Bay area, fire losses resulting from a M8.3 northern San Andreas fault earthquake–a repeat of the 1906 San Francisco earthquake–would range from $9 billion to $15 billion. The National Committee on Property Insurance (NCPI), an association of property and casualty insurers, estimates that residential and commercial property losses due to direct shaking will be $13 billion and $11 billion for events on the Newport-Inglewood and northern San Andreas faults, respectively (see Table 2.1). Altogether, the NCPI estimates that insurance losses from shaking damage, fire following earthquake, workers' compensation and general liability associated with a single catastrophic earthquake in California could range from $30 billion to more than $50 billion.[1]

1 We note that the NCPI loss estimates are highly sensitive to various assumptions regarding the earthquake scenario including the location and time of the event, weather conditions, and resulting patterns of shaking and collateral damage. It is possible to conceive of scenarios where losses could be greater or less.

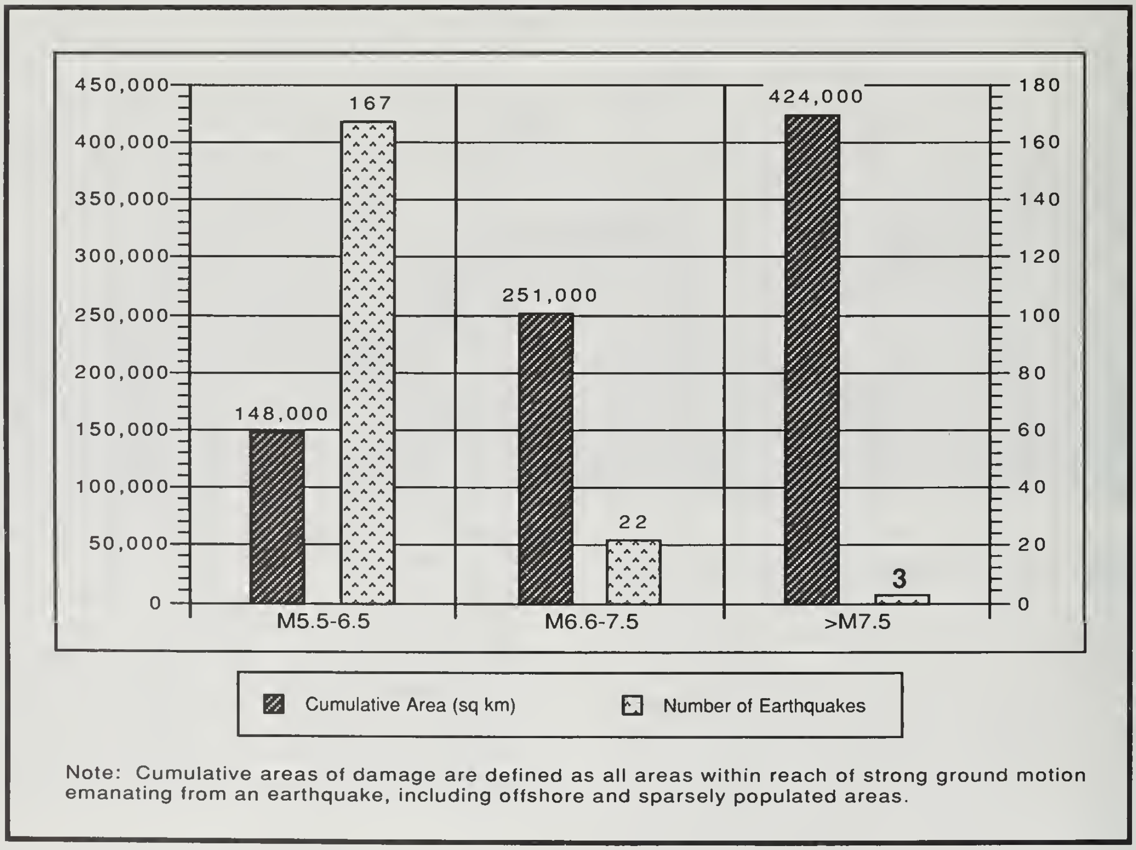


Figure 2.1. Damaging earthquakes in California, western Nevada, and northern Baja California, 1900-1987.

Based on these estimates, a major earthquake in southern or northern California could have wide-reaching effects on the insurance industry. If the insured losses were as high as these numbers suggest, insurers and reinsurers might be expected to be affected in a number of ways. Some insurers and reinsurers (companies which insure a portion of the risk of primary insurance companies) would be:

- overwhelmed by the volume of losses and unable to meet their claims obligations. The assets of the companies would be liquidated but the losses experienced by the insureds might go unpaid or paid at levels below the adjusted claim amount.
- forced to liquidate a large amount of assets to pay their claims. As a result, the stock and bond markets could be flooded with securities and bonds, depressing the price of these financial instruments and temporarily drying up fund sources for new security or bond issues.
- required to liquidate a portion of their assets to pay outstanding claims but would otherwise be well-positioned to pay the resulting claims.

In general, the insurance industry has coped with the dilemma of catastrophic potential under uncertainty by (1) ceding a portion of their earthquake risk to reinsurers, (2) using high deductibles to reduce exposure to a catastrophic earthquake and to effectively discourage earthquake insurance purchases in certain areas, (3) attempting to assess the earthquake hazard more completely, and (4) proposing federal legislation which would create a federal earthquake insurance corporation.[1]

In California, earthquake insurance is available in two different lines of coverage–personal and commercial. Personal lines of earthquake insurance are made available as endorsements to the policies sold to homeowners and renters. Residential earthquake insurance is generally available at a premium rate of $1.50-$2.00 per thousand dollars of replacement value with a deductible ranging from 5 to 20 percent, although the most common deductible seems to be 10 percent (U.S. Senate Committee on Commerce, Science and Transportation, 1987). Since January 1, 1985, insurance companies selling residential insurance in California have been required to offer earthquake insurance when a new homeowner's or renter's policy is written. Perhaps as a consequence of this "mandated offer" and damaging earthquakes occurring in 1983, 1984, 1986 and 1987, total earthquake insurance premiums earned have soared (see Figure 2.2). During the period from 1983 to 1988, total earthquake premiums have increased by more than $200 million (295 percent). Concurrently, total losses rose by about $30 million.

1 The proposal, known as the Earthquake Project, is contained in a report entitled "Catastrophic Earthquakes: The Need to Insure Against Economic Disaster prepared" by the National Committee on Property Insurance. In summary, the proposal calls for (1) establishment of a federal earthquake insurance corporation to insure federally-backed mortgages, and (2) a federal reinsurance program.

Table 2.1. Estimated insurance losses/exposures in southern and northern California (dollars in billions).

		ESTIMATED LOSS
Los Angeles Basin		
Newport-Inglewood (M7.5):		
Residential Property Damage		$2.3
Commercial Property Damage		11.2
Fire Following		24.3
Workers' Compensation		4.5
General Liability		10.1
	Totals	$52.4
San Francisco Bay Area		
San Andreas (M8.3):		
Residential Property Damage		$3.4
Commercial Property Damage		8.1
Fire Following		11.6
Workers' Compensation		2.4
General Liability		5.5
	Totals	$31.0

Sources: National Committee on Property Insurance. *Catastrophic Earthquakes: The Need to Insure Against Economic Disaster*, March 1989. "Earthquakes and the Insurance Industry. *Natural Hazards Observer*. November 1989.

In 1987, the year of the Whittier Narrows earthquake, insured losses were $47.6 million.[1] Although the Whittier Narrows earthquake generated substantial claims, the resulting losses were only about 23 percent of premiums earned. Although final data are not yet available, estimates of insured losses from the 1989 Loma Prieta earthquake are approximately $1.1 billion.[2] This estimate, however, includes losses from fire, allied, homeowners multiple peril, commercial peril, earthquake, inland marine, workers' compensation, general liability, auto physical damage and business interruption lines. In comparison, the total premiums earned and losses incurred by all California fire, casualty, and allied lines were $30.9 billion and $20.4 billion, respectively.[3]

The insurance industry appears to have responded to the increased demand for earthquake insurance by raising the deductible limits from 5 percent generally to 10 percent or more beginning in 1985. The change in the deductible levels reduced the overall catastrophic damage levels, as measured by Probable Maximum Loss (PML) estimates[4] prepared by the Department of Insurance (DOI). The change in the deductible levels appears to have had a greater disincentive effect on commercial earthquake insurance underwriting than on the residential earthquake insurance market. As shown in Table 2.2, while commercial PMLs fell by 8 percent between 1984 and 1987, residential PMLs increased by more than 100 percent.[5] Commercial PMLs declined dramatically from 1984 to 1985, probably due to increased deductibles and reduced sales resulting from increasing insurance rates.

1 *Underwriters' Report.* Statistical Review Number. May 23, 1988.
2 "Quake Insured Losses Expected To Hit $1 Billion." *Underwriters' Report,* December 14, 1989, p. 12.
3 *Underwriters' Report.* Statistical Review Number. May 25, 1989.

4 The PML is the expected structural damage dollar loss resulting from a magnitude 8.3 earthquake and is based on expected damage loss ratios to various building types. The Department of Insurance (DOI) annually requests information from insurance companies doing business in California regarding the number, type, and values of earthquake-insured buildings. The PML estimate is used by the DOI as a means of evaluating the financial solvency of an insurance company should a catastrophic earthquake occur.
5 Using the DOI's definition of PML, the PML from insured risks in the Los Angeles area cannot be added to PMLs from San Francisco because we would not expect two catastrophic earthquakes to occur simultaneously. PML, however, may also be viewed as a measure of exposure. The total PML exposure to the Los Angeles area in 1987 was $6.1 billion and the PML exposure to San Francisco was $4.4 billion. The total PML exposure in 1987 would be less than the sum of southern and northern California PML exposures because of the small conditional probability of two catastrophic earthquakes occurring. Over a long enough period of time, however, both catastrophic earthquakes would occur and the total PML exposure would be the sum of the PML exposures, or $10.5 billion.

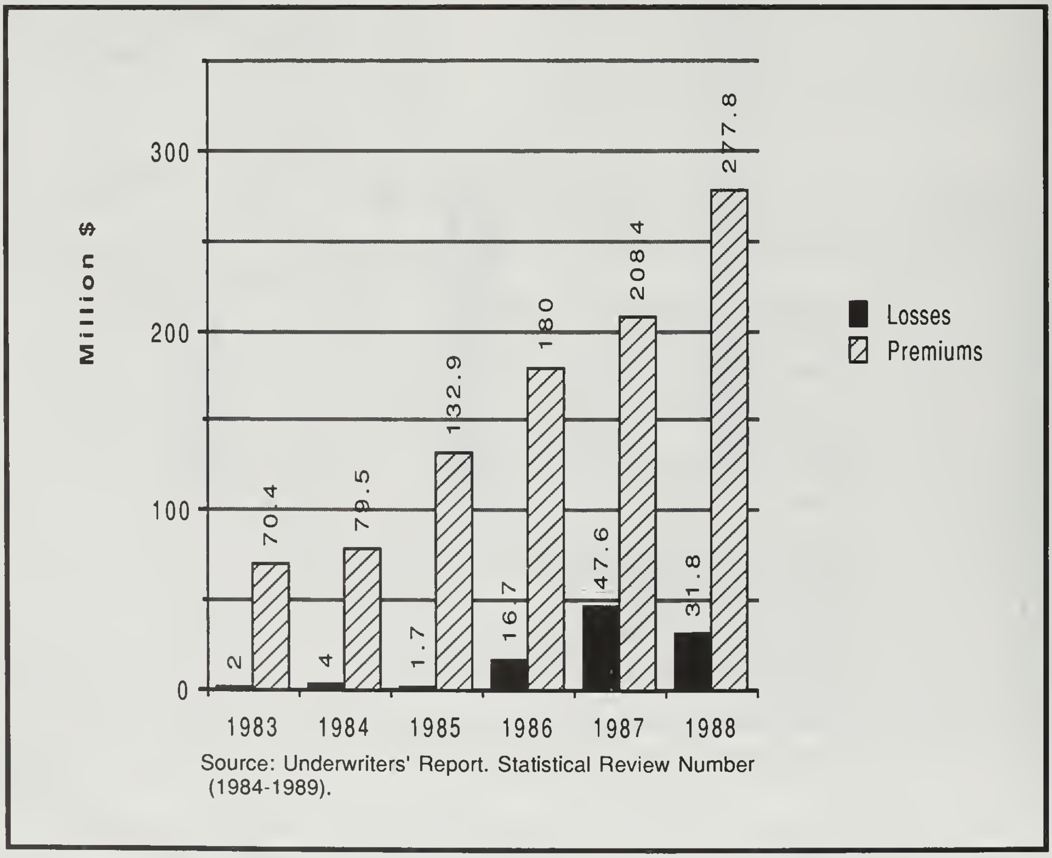


Figure 2.2. Earthquake insurance premiums earned and losses paid in California, 1983-1988.

Table 2.2. Probable maximum lc[illegible] fornia (dollars in millions).

Class & Location	1984	1985	1986	1987	1985-87 % Change
Residential					
Los Angeles	508	839	1,059	1,065	110
San Francisco	510	846	1,020	1,011	98
Totals	1,018	1,685	2,079	2,076	104
Commercial					
Los Angeles	5,427	4,093	4,198	5,039	-7
San Francisco	3,758	2,848	3,046	3,435	-9
Totals	9,185	6,941	7,244	8,474	-8
Grand Totals	10,203	8,626	9,323	10,550	3

Source: California Department of Insurance. California Earthquake Zoning Maximum Loss Evaluation Program, 1988. (Years correspond to year of business-year minus one.)

In summary, the effect of the mandated offer, notwithstanding increases in deductibles, was to stimulate demand for residential earthquake insurance between 1984 and 1986. This result is borne out in recent research conducted regarding the earthquake insurance purchase decision.[1] The increase in deductibles and insurance rates appears to have reduced the amount of commercial earthquake insurance coverage.

Although insurance companies' portfolios are taking up more of the less volatile residential earthquake insurance risk,[2] the premium cost of earthquake insurance as a percentage of total PML has more than doubled. While premiums nearly triple between 1983 and 1987, total PMLs have only risen by [illegible] percent (see Figure 2.3a).[3] As Figure 2.3b shows, the total premiums earned as a percentage of the total PML has more than doubled between 1983 and 1987, far in excess of the general inflation increase of 18 percent during the same period. Thus, for a given level of catastrophic risk, the cost of earthquake insurance has increased dramatically.

The increased cost of earthquake insurance may reflect greater nervousness on the part of insurers, particularly with respect to commercial risks. In addition, the industry, which is unable under California law to exclude certain residential risks, may be responding to increasing residential exposures by limiting its commercial exposure, using rates and deductibles as disincentives.

In response to the threat of a catastrophic earthquake, insurers convened an international conference to discuss various issues and problems concerning earthquake insurance. The conference included sessions on the geological and seismological considerations of earthquake exposure, earthquake risk analysis, and insurance capacity. A significant effort is being made, as was demonstrated at this conference, to improve loss estimation methodologies. The 1985 Michoacan earthquake, which caused severe structural damage in Mexico City, and the 1988 Armenian earthquake demonstrate the effect that local soil conditions can have on building vulnerabilities (Seed and others, 1989; Borcherdt and others, 1989). Various insurance and reinsurance industry officials have expressed interest in a program which delineates areas of ground shaking amplification.

LOCAL GOVERNMENTS AND SEISMIC SAFETY

Seismic hazards and seismic safety considerations in California are governed by various State laws, and are generally implemented and enforced by local governments. Local government implementation of State seismic safety policy is accomplished under the authority of five major areas:

1 Palm, Risa. "Does a Mandated Insurance Offer Affect the Propensity to Purchase Earthquake Insurance?" Paper presented to the Society for Risk Analysis annual meeting, San Francisco, October 1989.

2 Residences, particularly wood-frame dwellings, are considered less vulnerable to earthquake risk than commercial facilities.

3 Technically, PMLs and reported premiums-earned are not directly comparable. While premiums are reported for earthquake insurance policies, *per se*, PMLs also include earthquake-insured risks that are covered by other insurance lines such as commercial and homeowners multiple perils. Thus, PMLs are a broader measure than premiums-earned although it is not clear to what extent multiple peril policies contribute to PML amounts. Nonetheless, we believe that the trend of greater premium amounts per PML is basically correct.

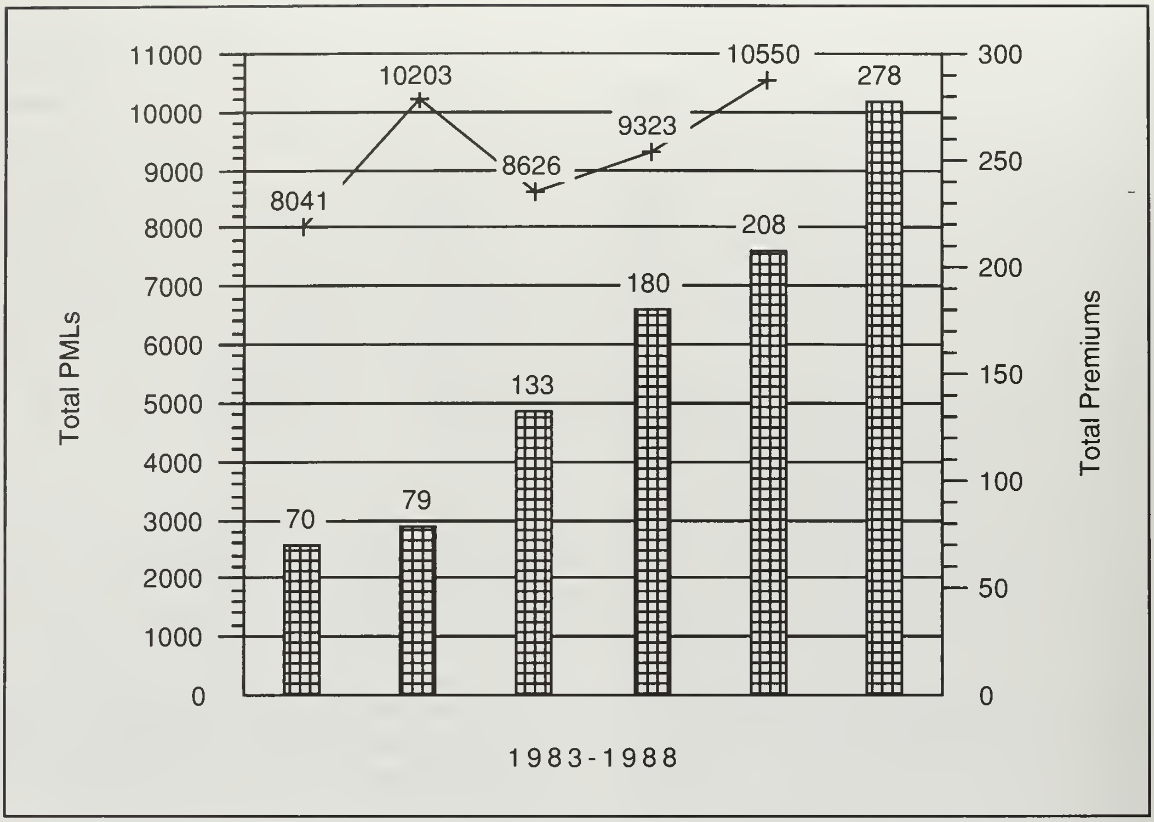
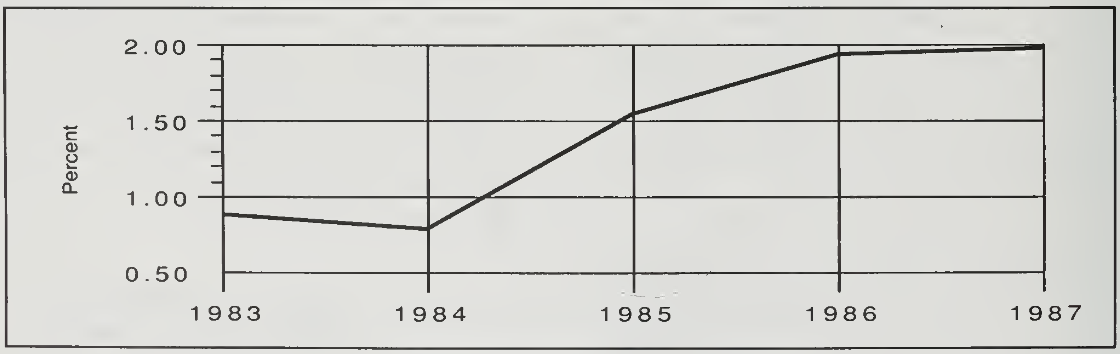


Figure 2.3a. Probable maximum loss estimates and premiums earned – 1983-1988.



Sources: *Underwriters' Report.* Statistical Review Number (1984-1989). California Department of Insurance. *California Earthquake Zoning and Probable Maximum Loss Evaluation Program.* 1988.

Figure 2.3b. Premiums as a percentage of probable maximum loss estimates, 1983-1987.

- Identification of seismic hazards and mitigation in the safety (or seismic safety) element of a community's general plan,
- Identification of seismic hazards and mitigation pursuant to the California Environmental Quality Act (CEQA),
- Use of fault rupture hazard zones (Alquist-Priolo Zones) identified by the State Geologist,
- Application of the Uniform Building Code (UBC) or the locally-adapted building code, and
- Identification of potentially hazardous (unreinforced masonry) buildings in specified areas of the state and establishment of a mitigation program.

This section details these earthquake hazard mitigation processes and briefly assesses their effectiveness. Finally, a seismic hazards mapping program undertaken by the Association of Bay Area Governments in the San Francisco Bay area is discussed.

Safety Element Process

Since 1937, all cities and counties have been required to adopt a comprehensive, long-term general plan for the physical development of the county or city. California Government Code Section 65302 specifies that the general plan include the following seven elements: (1) land use, (2) circulation, (3) housing, (4) conservation, (5) open space, (6) noise, and (7) safety.

The requirement to include safety and seismic safety elements in the general plan was prompted by wildland fires in the fall of 1970 and by the 1971 San Fernando earthquake. In 1984, Chapter 1009 consolidated these elements into a single safety element. Section 65302 specifies that the safety element address

> "protection of the community from any unreasonable risks associated with the effects of seismically induced surface rupture, ground shaking, ground failure, tsunami, seiche, and dam failure; slope instability leading to mudslides and landslides; subsidence and other geologic hazards known to the legislative body; flooding; and wildland and urban fires. The safety element shall include mapping of known seismic and other geologic hazards."

Thus, the safety element contains the basic set of policies regarding land-use decisions in hazardous areas.

The success of the safety element process in protecting the health and safety of the community has been reviewed and documented in several reports by independent researchers (Wyner and Mann, 1986; May and Bolton, 1986) and the California Seismic Safety Commission (1977; 1985) between 1977 and 1985. In general, these reports indicate that the safety element process has been most useful in educating local officials and increasing public awareness about seismic hazards. The policies included in safety elements, however, do not necessarily lead to specific hazard reduction activities by local officials. Moreover, safety elements have apparently had little direct impact on land-use decision-making. This is partly because land-use decisions frequently involve several factors including open space requirements, the economic benefits of a development, and a community's values and aspirations. In addition, information used in seismic safety elements may not support effective policy making.

Information gathered from the California Department of Conservation's Division of Mines and Geology, and the Governor's Office of Planning and Research (1988) reveals that all 58 counties and 98 percent of cities have completed a safety element. The DMG report (Alexander, 1988) indicates that the percentage of elements prepared prior to 1984 was 74 percent for counties and 58 percent for cities. Thus, while nearly all cities and counties have completed safety or seismic safety elements by 1989, most of these elements reflect information that is more than five years old.

During the last five years, however, information about the state's geology has increased dramatically. Since 1984, the State Geologist has issued, under the Alquist-Priolo Special Studies Zone program, 109 new maps and 28 revised maps (Hart, 1988). In addition, two earthquakes–the 1983 Coalinga and 1987 Whittier Narrows–have occurred on previously-unidentified faults. If the effectiveness of the safety element process in mitigating earthquake hazards is only as good as the geologic data on which it is based, the usefulness of safety elements as bases for hazard reduction measures must be questioned. Accordingly, a 1985 California Seismic Safety Commission report[1] indicated that since most jurisdictions do not commit funding for basic seismic and geologic studies, the State should seek to provide information about seismic hazards.

California Environmental Quality Act Process

The California Environmental Quality Act (CEQA) was enacted in 1970 to ensure that local agencies consider and address the environmental implications of projects

1 California Seismic Safety Commission, Seismic Safety Element Review Committee. *A Review of the Seismic Safety Element Requirement in California* Report No. SSC 85-05. Sacramento: California Seismic Safety Commission, 1 August 1985.

approved under their auspices. CEQA requires that an environmental impact report (EIR) be prepared for projects which will result in significant effects to the environment. Moreover, CEQA specifies that local agencies implement feasible mitigation measures or feasible alternatives identified in EIRs for projects that cause significant adverse impacts.

In the case of geologic and seismic hazards, a project EIR must properly identify such hazards and mitigation measures. Local agencies, therefore, have California statutory authority to regulate private development projects through the geologic and seismic hazards portion of the EIR. The statutory authority embodied in CEQA provides local agencies with ready-made provisions which may exceed either the general plan policies or local ordinances. In addition, CEQA provisions are enforced by and appealed to judicial, rather than legislative, bodies. Thus, compliance with CEQA is not easily subverted by appeals to local elected officials. For this reason, CEQA provisions are considered to be a powerful tool for local agencies in ensuring that geologic and seismic hazards are considered and mitigated. On the other hand, CEQA does not specify how specific hazards are to be mitigated. Thus, mitigation measures must be evaluated on a case-by-case basis with little guidance for local officials or the courts which are called on to resolve these disputes. In addition, the effectiveness of CEQA in mitigating hazards is directly related to the adequacy of information on seismic hazards. Since the availability of seismic hazard information varies considerably between jurisdictions, the effectiveness of the CEQA review process is bound to be inconsistent.

Alquist-Priolo Special Studies (Fault Rupture) Zones

The Alquist-Priolo Special Studies Zones Act was enacted in 1972 to ensure that structures for human occupancy are not built over a trace of an active fault. The Act, administered by the DMG, requires the State Geologist to delineate special studies zones to encompass all potentially and recently active traces of faults which constitute a potential hazard to structures from surface faulting or fault creep (Hart, 1988). For their part, cities and counties must require a geologic report defining and delineating any surface fault rupture hazard for those projects located within special studies zones (SSZ), prior to approval of the project. The Act further requires that real estate agents, or sellers of real estate acting without an agent, disclose to prospective purchasers the fact that the property is located within a delineated special studies zone.

Until recently, there has been no comprehensive review of the level of compliance of local agencies with the Alquist-Priolo Act, although there have been studies on other aspects of the Act, such as the disclosure requirements of the Act, compliance by real estate agents, and the importance of fault zone information in mortgage lending decisions. A study conducted between 1977 and 1980 concluded that:

> "the land-use planning aspects of the Alquist-Priolo Act are being implemented in a way that meets the basic objectives of the law. Few, if any, structures are being built astride known faults; seismic safety issues in the SSZs are being aired publicly, and are being included in the decision-making process; and knowledge about the location of major faults is gradually accumulating. In short, this specific and limited effort at state intervention in local land-use planning seems successful."[1]

In fall 1989, the DMG issued a contract to study the effectiveness of the State's program, including an assessment of the level of compliance with the Act by local government. The study was recently completed and concludes that although the Alquist-Priolo Act has been effective in reducing earthquake risk in California, the required special studies and their review by local government vary greatly in quality. It was concluded that the level of compliance with the Act could be improved by requiring that site investigations and their review be done by a certified engineering geologist, that cities and counties retain such staff, and that the DMG prepare more comprehensive guidelines for site investigations and encourage greater communication of seismic hazard information between local jurisdictions.[2]

Uniform Building Code

The Uniform Building Code (UBC) is a model code developed by the International Conference of Building Officials describing recommended construction conditions and practices. The purpose of the UBC is to "provide minimum standards to safeguard life or limb, health, property and welfare."[3] The UBC contains specific provisions for ensuring that buildings are able to sustain the lateral forces generated by an earthquake.[4] Typically, local governments in California adopt the UBC, or an amended version of the UBC, as a minimum building standard. Code enforcement is generally vested in the building official function of local government.

1 Wyner, Alan J. and Dean E. Mann. *Preparing for California's Earthquakes: Local Government and Seismic Safety.* University of California, Berkeley: Institute of Governmental Studies, 1986.
2 Reitherman, R. and D. J. Leeds. A Study of the Effectivenees of the Alquist-Priolo Program. The Reitherman Company, Half Moon Bay, California, 1990.
3 International Conference of Building Officials. *Uniform Building Code*, 1988.
4 The National Earthquake Hazards Reduction Program has published standards for various types of federal facilities. In addition, there are special exceptions to the UBC for critical facilities such as Title 24 of the California Administrative Code for hospitals and schools, Nuclear Regulatory Commission criteria for nuclear power plants, and criteria for dams and freeways developed by federal and state agencies.

Enforcement of the building code is the primary regulatory tool used by local governments to ensure seismic safety. Generally, since planning departments are unable or unwilling to foreclose all development within seismically hazardous areas, the building official is called on to ensure that the proposed project meets the seismic safety provisions provided in the building code (French and Harmon, 1982; Wyner and Mann, 1983; California Seismic Safety Commission, 1985; Berke and Wilhite, 1988). The code addresses lateral force requirements to resist shaking, importance of the structure relative to its occupancy characteristics, the seismic zone, and four types of soil which affect shaking levels (International Conference of Building Officials, 1988).

Despite these systematic considerations, recent testimony by F. Turner and A. Patwardan of Woodward-Clyde Consultants before the California Seismic Safety Commission indicates there may be several problems with the seismic safety provisions in the UBC.[1] The building code is described as a minimum design condition. It, however, is often the maximum level to which buildings are designed. Specifically, the earthquake performance objectives of the seismic safety provisions in the UBC, developed by the Structural Engineers Association of California (SEAOC), specify that buildings (1) resist damage from minor earthquakes, (2) experience some nonstructural damage from moderate earthquakes and (3) incur nonstructural and some structural damage from major earthquakes. These performance objectives, however, conflict with the objectives of the UBC because a serious loss of life or limb, as well as substantial losses to property could occur in a seismically-designed facility even though the SEAOC seismic design objectives of preventing catastrophic failure are met.

Recommendations for changes in the UBC seismic design criteria are developed by the SEAOC and submitted to the International Conference of Building Officials for inclusion in the next version of the UBC, which is revised every three years. The seismic design provisions, therefore, are exclusively developed by a private organization based on its expertise and judgment. According to Turner and Patwardan, as a result, building owners and the public are generally not aware of the level of risk inherent in the UBC, and have not participated in decisions regarding the acceptable level of risk. This has been found to be true for public officials as well (Wyner, 1982).

Finally, the UBC's lateral force requirements include factors such as the ground shaking characteristics of soils, relative weights given to construction in seismic zones, and importance factors assigned to different occupancy types. H.B. Seed, an eminent soils engineer, suggested in remarks to the Seismic Safety Commission in February 1989 that one of the soil factors used in the 1988 UBC may result in lateral force design levels which are less than expected levels of shaking in California.[2] Thus, certain buildings in these soils may experience damage similar to that observed in Mexico City in 1985.[3] Given (1) the conflict between the performance objectives of the UBC and the SEAOC seismic design provisions, (2) building owners and the public's lack of awareness of and participation in the acceptable level of risk implicit in the UBC, and (3) potential problems with judgmental factors used in formulating seismic design levels, sole reliance on the UBC's seismic design criteria for protecting a community's health and safety in areas of unusually high hazard potential may be ill-advised.

Unreinforced Masonry Buildings

Government Code Section 8875 et seq established the Unreinforced Masonry Law (URM) in 1986 to require all cities and counties in Seismic Zone 4 (California coastal areas, except portions of San Diego, and southern Sierra regions) to identify hazardous unreinforced masonry buildings in their jurisdictions by January 1, 1990. The URM Law also requires local agencies to initiate a mitigation program and notify building owners that their buildings are potentially hazardous in earthquakes. Mitigation programs are at the discretion of the local agencies and may include standards and priorities for reinforcing and demolishing hazardous buildings. Although implementation of the URM Law has just begun, it is likely to have a significant impact on the earthquake risk within communities. The 1989 Loma Prieta earthquake provided a dramatic reminder of the hazards posed by these buildings in Santa Cruz and San Francisco.

OTHER USES

Other uses of seismic hazard information include public information activities, disclosure of hazards to prospective purchasers in the course of property transactions, and emergency response planning.

Public Information

Information which is generated in preparing a safety element for the general plan, the CEQA process, and Alquist-Priolo zone maps at the state and local level are publicly available. In addition, the DMG prepares earthquake planning scenarios for various possible events, which are issued publicly and made available at publication cost.

1 California Seismic Safety Commission. Minutes of Regular Meeting, August 10, 1989.

2 California Seismic Safety Commission. Minutes of Regular Meeting, February 9, 1989, San Francisco.

3 Seed, H. Bolton and Joseph Sun. "The Need for an S4 Site Factor." Summary paper, no date.

General plan revisions are typically presented in formal hearings to the public for their comment and participation prior to adoption. These hearings, however, often address the broad range of issues contained in the various elements within a general plan, of which seismic safety is but one. The CEQA process similarly involves consideration of a broad range of issues. As a result, seismic safety issues in general plans and CEQA documents may be overshadowed by other, more pressing concerns.

Beginning in the late 1970s, the Association of Bay Area Governments (ABAG), with the financial support of the U.S. Geological Survey, began preparing a series of maps detailing the ground shaking hazard in the San Francisco Bay area. The series includes ground motion estimates and maximum shaking intensity for the region. In addition, the map series contains estimates of damage to tilt-up concrete buildings, concrete and steel buildings, and wood-frame dwellings expressed as the cumulative expected damage. Aside from products provided by the Alquist-Priolo Special Studies Zone program, these maps represent the most extensive use of areal earthquake hazards information for local government application. Unlike previous hazard mapping efforts which display potential damage in a general fashion or with regard to a specific earthquake scenario, these maps depict the *relative risk* of various types of structures within the region to *cumulative* earthquake sources. Thus, the ABAG maps attempt to estimate risk, based on current knowledge about ground motion, local geology, and building vulnerabilities.

The State of California undertakes seismic hazard public information activities through three different agencies–California Seismic Safety Commission, DMG and the Governor's Office of Emergency Services. The Governor's Office of Emergency Services provides information through two earthquake preparedness projects–the Bay Area Regional Earthquake Preparedness Project (BAREPP) and the Southern California Earthquake Preparedness Project (SCEPP). These bodies provide informational materials and respond to specific inquiries.

Disclosure of Special Studies Zones

The Alquist-Priolo Special Studies Zones Act specifically requires real estate agents and sellers to disclose the presence of a special studies zone to prospective buyers. In addition, at least one local jurisdiction–Santa Clara County–requires all sellers of real estate lying partly or wholly within the county's flood, landslide, and fault rupture zones to provide the buyer with a written statement of the geologic risk. As a consequence of these requirements, the California Association of Realtors has produced disclosure forms for use in real estate contracts. In the San Francisco Bay area, five local boards of real estate agents prepared maps depicting the designated flood, landslide, and fault rupture zones for use by members in meeting general disclosure requirements.

The disclosure requirement in the Alquist-Priolo Special Studies Zone Act was studied in a 1981[1] report. The study found that earthquake insurance inquiries and purchases were higher among in-zone buyers, suggesting that disclosure generated greater consideration of earthquake risk. The study, however, concluded that the disclosure process is not effective in providing information for informed choices because not all real estate agents fully understand the zones and/or support the disclosure process. In addition, because disclosure of seismic hazards is often provided at the final stage of the home purchase process–closing of escrow–buyers may be unable or unwilling to use the information provided. Notwithstanding these deficiencies, the study recommends that disclosure be broadened to include other seismic hazards which represent a greater part of earthquake risk, such as liquefaction, shaking, and ground failure.

Emergency Response Uses

There are no specific State requirements that geohazard information be used in emergency response activities, although there are provisions for utilizing earthquake prediction research and warnings by the Governor's Office of Emergency Services. Nonetheless, efforts at the State level have been made to provide earthquake hazards information for disaster planning purposes.

The DMG has prepared a series of earthquake planning scenarios since 1982 providing data on expected shaking intensity, collateral effects, and distribution of damage to lifeline facilities such as highways, airports, railroads, marine facilities, communications, water and waste, and energy production and conveyance systems. These scenarios have been prepared expressly to assist local and State officials in emergency preparedness planning. The scenarios have included the following earthquakes:

M8.3, San Andreas fault in southern California,
M8.3, San Andreas fault in the San Francisco Bay area,
M7.5, Hayward fault in the San Francisco Bay area, and
M7.5, Newport-Inglewood fault in the Los Angeles area.

In addition, the DMG is completing work on a scenario for San Diego (Rose Canyon and Silver Strand faults) and for San Bernardino and Riverside counties (San Jacinto fault).

---

1 Palm, Risa. *Real Estate Agents and Special Studies Zones Disclosure: The Response of California Home Buyers to Earthquake Hazards Information.* Boulder, CO: Institute of Behavioral Science, University of Colorado, 1981.

CHAPTER THREE—EARTHQUAKE INSURANCE

The insurance industry has recently expressed increasing interest in improved earthquake hazard information (U.S. Geological Survey and California Department of Insurance). This increased interest is probably due to the publication of several scenario reports since 1980 by the Federal Emergency Management Agency (FEMA), the California Department of Conservation, Division of Mines and Geology, and industry research groups (as well as the occurrence of a number of damaging earthquakes in California beginning in 1983). These studies have pointed out how areas in the Midwest, the East Coast, and particularly California may be impacted by earthquakes. In 1980, FEMA published estimates of damages and fatalities for earthquakes along the San Andreas, Hayward, and Newport-Inglewood faults. As mentioned earlier in this report, the All-Industry Research Advisory Council has published estimates of insured losses from fire following earthquake, workers' compensation and general liability, and property losses. The DMG has published planning scenarios for earthquakes on the southern and northern San Andreas fault, the Hayward fault in the San Francisco Bay area, and the Newport-Inglewood fault zone near Los Angeles. All of these reports, although prepared for different purposes and audiences, estimate the lifeline impact that may result from any one of several major California earthquake sources.

For the purposes of this report, use of seismic hazard information by the insurance industry may be separated into uses by (1) earthquake insurance risk modelers and (2) insurance companies. Earthquake insurance risk modelers include those organizations that have developed formal and verifiable approaches to assessing the risk of earthquake insurance losses and/or establishing "actuarially-sound" earthquake insurance rates. In this chapter, we will review the general methods used by several earthquake risk modelers and the uses of hazards information by insurance companies. There are, of course, many other firms and organizations that provide earthquake risk estimates. The firms that are reviewed in this report, in our opinion, fairly represent the approach and methods of many earthquake risk modelers.

Insurance companies, for their part, may use the services of the modelers for risk determination, portfolio management, or merely as another source of information in earthquake insurance underwriting. Insurance firms may also use less formal approaches, depending on the type of insured risk. To find out how insurance companies currently use seismic hazard information, we evaluated responses from a questionnaire provided to the National Committee on Property Insurance for distribution to members of its Special Earthquake Study Committee. In addition, we evaluated surveys mailed to other selected insurance firms and interviewed earthquake insurance executives in several companies.

This chapter, therefore, will provide information on the monetary loss estimation methods, generally, and on current uses of seismic hazard information by modelers and insurance companies, based on the surveys and interviews with these organizations. In addition, we will report on anticipated needs for more detailed or improved seismic hazard information by these concerns.

MONETARY LOSS ESTIMATION

Earthquake monetary loss estimation, in general, is difficult and complex. The complexity arises from the system of variables that must be assessed and the associated uncertainty. There are uncertainties in earthquake fault sources, patterns of shaking, site effects, building damage, effects of collateral hazards (such as liquefaction, landslides, and fault rupture), and other loss conditions such as fire following earthquake. Figures 3.1a and 3.1b show the many areas of variability and uncertainty that go into loss estimation.

Monetary loss estimates from damage to structures generally involve one of two methods: (1) the Probable Maximum Loss (PML) method developed by Karl Steinbrugge and Ted Algermissen for the Insurance Services Office (ISO), and (2) the ATC-13 method developed by the Applied Technology Council. These methodologies are based on the propositions that:

- earthquake magnitudes and fault rupture lengths may be effectively converted into Modified Mercalli Intensity (MMI) patterns,
- MMI attenuates as the distance from the causative fault increases,
- monetary losses are directly related to MMI and the type and value of structure.

Thus, monetary loss of a given structure or set of structures under both of these methods can be estimated if the MMI, building type and the value of the structure are given. These methods, however, are intended to model *average* monetary losses and are not intended to provide loss estimates for a specific structure. Both the ISO and ATC methods yield similar results for similar structure types.

The PML building classification system used by ISO includes 21 categories of buildings, based on the information that is readily available to insurance companies. The PML numbers developed for ISO are based on experience with California earthquakes and expert judgment.

The ATC-13 study includes 41 classes of building structures, as well as classes for other structures such as bridges, pipelines, dams, tunnels, and others. The mean damage factors developed in this report are based on an amalgamation of expert opinions, using the Delphi method, weighted by the experience of the participants.

Other Losses

There have been other attempts to estimate monetary loss resulting from other losses such as damage to contents, fire following earthquake, and insurance claims for workers' compensation and general liability. Damage to contents is generally estimated as a proportion of structural monetary losses (approximately 50 percent). The results from studies on fire following earthquake and other insurance claims are highly dependent on the earthquake assumed, and other prevailing conditions such as season, time of day, meterological conditions etc., and cannot generally be used in a loss estimation procedure. One model reviewed below–*IRAS* developed at Stanford University–has incorporated a fire following earthquake algorithm into its estimates.

EARTHQUAKE INSURANCE RISK MODELERS

Our review of modelers includes two consulting firms, an industry organization, an insurance company that has developed its own risk assessment system, and a university. In some cases, these organizations provided detailed information on the methods and data used in their risk assessment procedures. In other cases, an outline of the general approach was given. The organizations interviewed include the Allstate Research and Planning Center, E.W. Blanch Company Reinsurance Services, EQE Engineering, Insurance Services Organization, and Stanford University. In addition to these organizations, we discussed loss estimation methods with personnel at two earthquake risk consulting firms, Crisis Management and Dames & Moore, and the U.S. Geological Survey. Our review of earthquake loss estimation models, however, will focus on the methodologies employed by the former organizations.

Allstate Research and Planning Center

This organization (a research arm of the Allstate Insurance Company located in Menlo Park, California) has developed the *Allstate Earthquake Loss Model* to provide the company with information about its potential exposure in residential lines of insurance. Allstate indicated that the model is used to estimate losses but not to set earthquake insurance rates because "rates are set in the marketplace." The model, however, was used to develop the rate schedules included in the Earthquake Project's legislative proposal before the U.S. Congress.

Allstate's Model uses input on earthquake faults, magnitudes, epicenters, and a deductible level. The model then simulates a series of earthquakes for a range of magnitudes for all faults, estimates the mean Modified Mercalli Intensity near the fault ruptures, attenuates the intensities as the distance from the faults increases, and, using ATC-13 damage-loss factors, estimates damage to low-rise wood-frame and low-rise unreinforced masonry buildings. Losses are estimated and summed by zip code for all zip code centroids located within the damaged areas. In addition, the model is able to simulate long-term expected annual losses from a given fault by calculating the average losses for various magnitude earthquakes based on the probabilities associated with each magnitude. Allstate indicated that the simulated losses associated with the 1987 Whittier earthquake were within 5 percent of actual losses to the company. Based on these results, Allstate believes that the model is satisfactorily accurate.

Current/Anticipated Uses of Geohazard Data. Allstate's model does not include any surface or subsurface geological information. Staff at Allstate indicate that soil factors were included in the model at one time but were removed because they had little effect on the results and were inconsistent with the ATC-13 approach used in the model. Allstate indicated that better ground/soils information would be useful if it could be used to adjust Modified Mercalli intensities. They noted, however, that soils data may have little effect on results if the affected areas represent a small percentage of a company's total exposure. For example, if total losses projected are 5 percent of the total exposures without the use of improved soils data, an increase in estimated total losses of, say, 20 percent resulting from improved soils data would generate losses that are 6 percent of total exposure. Thus, the importance of improved soils data depends on the proportion of potential exposure to the total exposure.

EQE Engineering

The EQE methodology is contained in *EQHAZARD* and includes seismotectonic modeling of faults, estimation of earthquake shaking intensity at sites, vulnerability ratios based on site intensity, and determination of the mean and higher fractile insured loss. Unlike other methods, however, *EQHAZARD* attenuates the peak ground acceleration to the site and then converts this value to Modified Mercalli Intensity. Vulnerability is computed

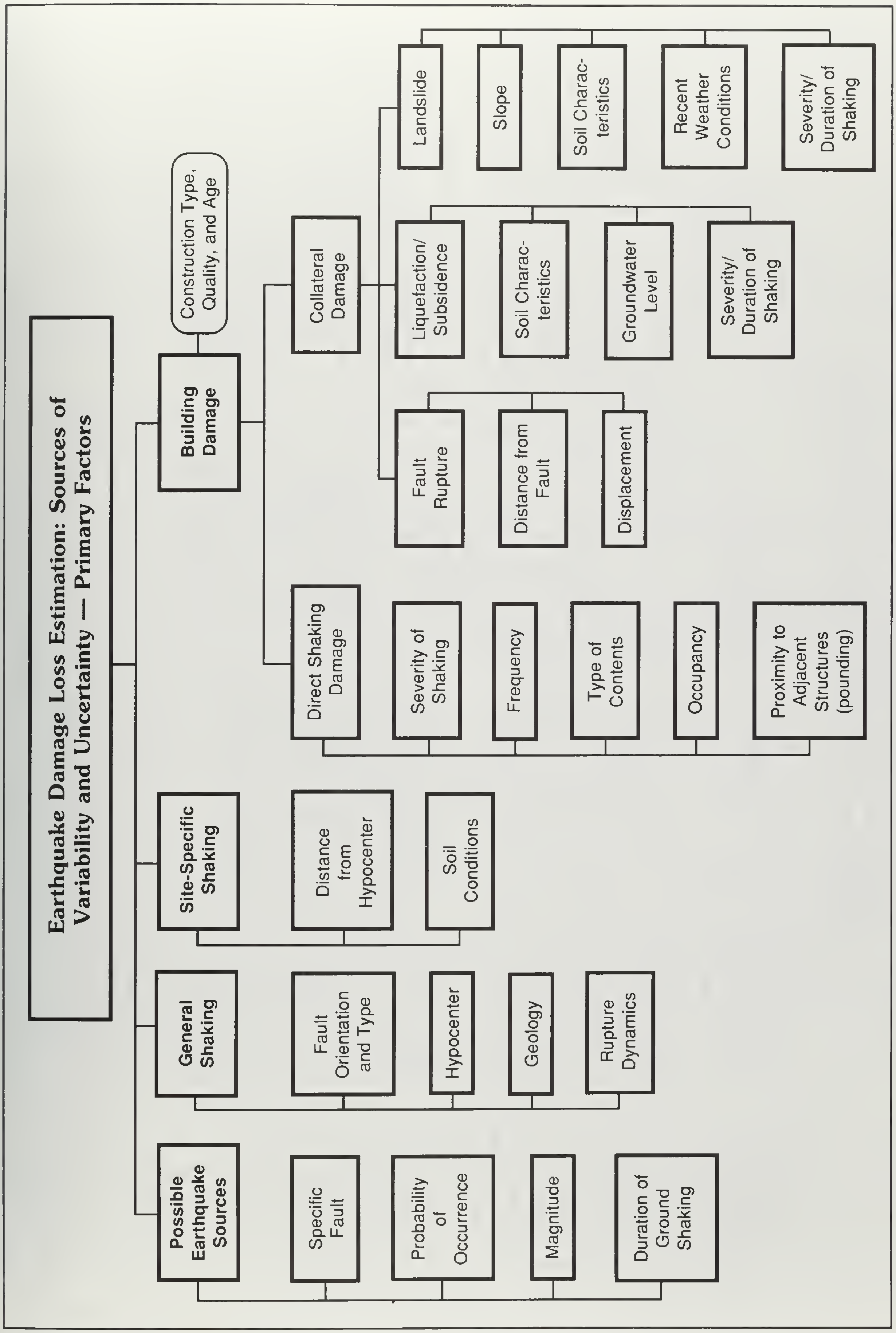


Figure 3.1a. Earthquake damage loss estimation: sources of variability and uncertainty — primary factors.

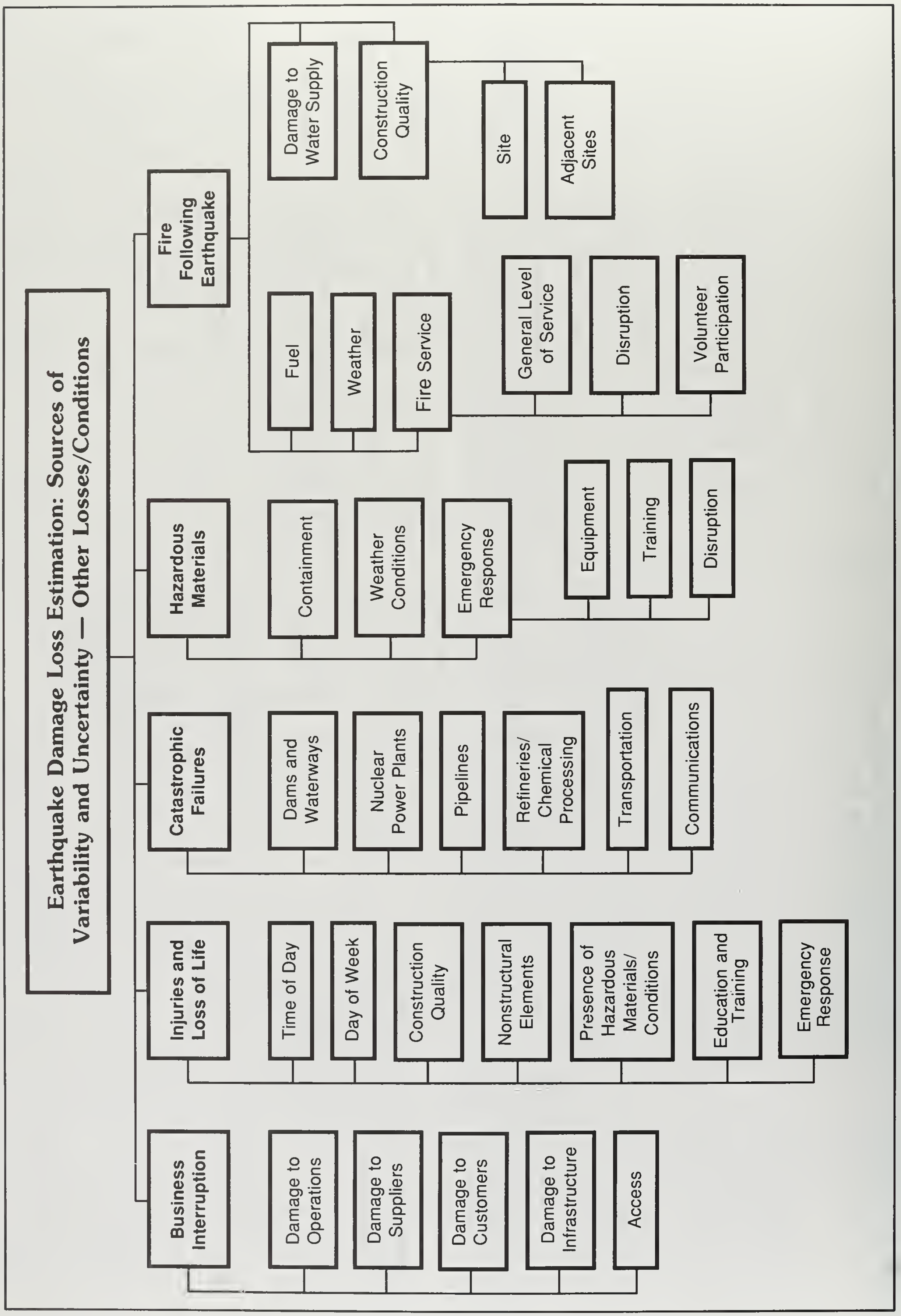


Figure 3.1b. Earthquake damage loss estimation: sources of variability and uncertainty and other losses/conditions.

based on the site MMI and loss ratios developed in ATC-13 and other sources. Finally, PML in *EQHAZARD* is estimated using the (maximum credible) earthquake with a return period of approximately 475 years from each potential earthquake source.

Current/Anticipated Uses of Geohazard Data. *EQHAZARD* computes MMI based on the site peak ground acceleration and adjusts these values in MMI increments based on the site soil conditions. The proprietary geohazard data used in *EQHAZARD* is derived from various sources. EQE indicates that improved geohazards data can be utilized to "develop cost-effective mitigation measures" and "improve the state-of-the-art" of loss estimation.

E.W. Blanch Company Reinsurance Services

E.W. Blanch's *CATALYST* earthquake model is based on the work of Karl Steinbrugge and the concept of probable maximum loss (PML). PML in *CATALYST* is defined as the average probable maximum monetary loss to structures which will be experienced by 9 out of 10 buildings in a given building class in a specified PML zone (within 6 miles of the fault rupture), assuming an earthquake of M8.2. *CATALYST* estimates risk based on expected damage ratios for certain building types at various distances from an earthquake fault rupture. Specifically, E.W. Blanch indicates that losses are calculated by modifying an initial building damage factor depending on the distance of the risk from the fault rupture, the presence of poor soil conditions, and whether the risk is a high-rise building. The initial damage factor by building type is based on the PML concept applied to facilities within 6 miles of the fault rupture. Fault rupture length is estimated by magnitude. Ground motion and intensity are not used directly in estimating losses but are implicit in the damage ratios and distance attenuation employed in the model. For residences, *CATALYST* uses the number of dwellings and the total value of properties by 5-digit zip code. Commercial risks are modelled using data by 5-digit zip code on construction class, height in stories, and insured value. The model uses the residential and commercial data along with the distance from the fault rupture of the quake and the soil conditions by zip code. The model provides estimates for 21 maximum credible earthquakes along ten major California faults.

Current/Anticipated Uses of Geohazard Data. According to E.W. Blanch, the soils data used in *CATALYST* are based on Steinbrugge's work and on U.S. Geological Survey data. Soils factors were developed by overlaying soils maps with zip code zones. The resulting factors are then used to adjust the PML ratios within each zip code. E.W. Blanch indicated that the soils element of the model needs improvement, and the company would be interested in soils data (organized by zip code) that reflect the quantitative effect of various soils on loss estimates.

Insurance Services Office

The Insurance Service Office (ISO), a service association for insurers, has prepared a *Guide for Determination of Earthquake Classifications* to assist insurers in establishing rate classifications for commercial buildings. The building classification system was based on PML estimates prepared by Karl Steinbrugge. The *Guide* places buildings into one of se›en earthquake insurance rate groups based on either the building classifications or on a system of rating points, with more earthquake-susceptible buildings receiving more points. Points are based on construction characteristics, size, shape, equipment, design, and quality control. Penalty points are added for site hazards such as faulting, foundation materials, and topography, exposure hazards such as pounding and overhanging elements, and roof tanks or heavy metal equipment hazards. The *Guide*, therefore, provides loss rating and rate classification information for insurers rather than loss estimates *per se*.

Current/Anticipated Uses of Geohazard Data. Under the ISO system, geologic information is reflected in penalty points given for sites located (1) within 2 miles of an active fault, (2) on alluvial soil, and (3) on ground slopes of 50 percent (30 degrees) or greater. Additional penalty points may have the effect of promoting a building into a higher rate group. The applicable rates for different rate groups are found in the *Commercial Lines Manual* published by ISO.

Stanford University

The Stanford University Department of Civil Engineering has developed an expert system for estimating earthquake losses known as the Insurance/Investment Risk Assessment System (*IRAS*). *IRAS* is intended to be a user-friendly, knowledge-based expert system for use by engineers, real estate investment analysts, insurance underwriters, and decision makers and can be used to assess individual risk, risk to a portfolio of properties, or regional risk. Although *IRAS* does not break any new ground in loss estimation methods, it incorporates the state-of-the-art knowledge of loss estimation.

IRAS allows the user to choose between the PML or ATC-13 (designated as SDT) methods when evaluating risk. At a minimum, *IRAS* requires the address, zip code, building type, year built, and replacement value of the structure(s) and contents. The system will then provide estimates based on a given scenario earthquake, maximum risk, classical risk (PML based on local MMI IX), and average risk over a specified time frame. In order to improve the confidence of the loss estimates, *IRAS* will consider other building-specific information such as the type of interior walls, the diaphragm and anchorage, and the roof system. *IRAS* will then generate a range of losses, an expected loss amount and a qualitative assessment of the reliability of the estimate–ranging from high to very low.

Current/Anticipated Uses of Geohazard Data. *IRAS* does use soils information to adjust ground shaking levels experienced at a specific site. The model does use geological information digitized by zip code and census tract to estimate losses from fault rupture and collateral hazards such as landslides and liquefaction. Qualitative assessments of these collateral hazards are transferred to numerical values using fuzzy set theory. The resulting factors are then used to estimate dollar losses.

Although *IRAS* does currently use soils information to adjust shaking losses, the authors of *IRAS* at Stanford University indicate that detailed geohazards information may improve the loss estimation capabilities of the model and would, therefore, be desirable. Ideally, this information would be available by latitude and longitude and would describe soil conditions, landslide potential, and liquefaction potential. In order to test the value of improved or more detailed soils information, we initiated an experiment with Stanford University to test the sensitivity of loss estimation methods in *IRAS* to soils information, using actual loss data provided by the California Department of Veterans Affairs.[1] The results of this experiment will be reported separately.

1 The Department of Veterans Affairs has been required by law to maintain a Disaster Indemnity Fund to insure against losses from floods and earthquakes by participants in the Cal-Vet Home Loan Program. The deductible, set by law, is $250. Thus, claims paid under this program describe a broader range of losses from earthquakes than private insurance programs which have 5 to 20 percent deductibles. The Department has recently begun systematically compiling this information for use in risk management.

INSURANCE COMPANIES

To collect data on current and anticipated uses of earth science information from insurers, project staff (1) circulated a survey to insurance companies under the auspices of the Earthquake Project at the National Committee of Property Insurance, and (2) had numerous discussions with insurance executives at an international meeting on earthquakes and insurance held in May 1989. In the survey, insurers were asked questions regarding their market share, use of loss estimation methods, current uses of earth science information, and what improved earth science information would be helpful. In addition, companies were asked: "In your judgment, what is the biggest problem in earthquake insurance?"

Project staff received ten completed surveys from insurance organizations–nine primary insurers and one reinsurer. The respondents indicated that earthquake premiums ranged from 0.6 percent to 25 percent of their total premiums. Approximately half of the insurers mostly sold commercial earthquake insurance. Most indicated that they reinsured a greater proportion of their commercial risk than residential risk, which is consistent with insurance company reports to the California Department of Insurance (DOI).

In terms of loss estimation methods, respondents indicated that they used methods prescribed by the DOI (4), ISO (4), or risk modelers (2–NTS and E.W. Blanch). Three indicated that they are considering the use of Stanford's *IRAS* model. Seven of ten respondents indicate that they systematically evaluate earthquake risks. Only four of ten use geological data in evaluating risk, two of which use it for large commercial risks. The sources of information used are the U.S. Geological Survey, private sources, and the DMG.

Nine of ten respondents desire such information at the zip code or postal carrier zone level. One indicated that

Insurance respondents indicated that the most useful geohazard information would be:

Ground shaking susceptibility	7
Fault rupture potential and proximity to faults	7
Ground failure potential	4
Liquefaction potential	4
Landslide potential	1

census tract detail would be useful. Respondents indicated that either the State or federal government should provide the data. According to the nine responding insurers, the biggest problem with earthquake insurance is uncertainty (5), financial capacity of the industry (2), adverse selection (1), and inability to set aside tax-free reserves (1).

Informal discussions with industry officials revealed a general interest in improved earth science information. Several officials, however, cautioned against presenting information at a high level of precision. Since there is considerable uncertainty in earthquake effects (shaking damage, fire following earthquake, and casualties) precise geohazards information may not be significant in current loss estimation methods. Rather, classifying areas according to relative risk could be useful in the insurance industry. Industry officials could then weight risk against these levels. One official indicated that improved geoscience information could have detrimental overall effects if certain residential insurance purchasers were priced out of earthquake insurance as a result of a new risk-based rating system.

CONCLUSIONS

Based on our review of insurance companies and earthquake insurance risk modelers, improved geohazards information would be useful in improving loss estimation activities. Indeed, insurers noted that the biggest problem in earthquake insurance is the uncertainty of earthquake effects. The desired scale of the information is at the zip code level, although information provided at other levels of detail would almost certainly be converted to zip code level by risk modelling consultants wishing to service the needs of insurers. At a conference organized to determine the earthquake risk information needs of the insurance industry, industry participants indicated an interest in seismic hazards information such as soil conditions, landslides, and liquefaction, particularly if the data can be translated into loss estimation parameters.[1] Several insurance officials expressed skepticism about overly precise information and suggested that maps which classify areas according to relative risk would be a tremendous improvement. Properties in these areas could be highlighted for special rates or deductibles. Risk consultants would desire data which can be directly translated or, in combination with other information, transformed into dollar loss amounts to suit the needs of their modelling capabilities. In general, both of these organizations look to the State or the federal government to provide this information.

Improved earth science information may serve another purpose. In his 1990 State of the State report before the Legislature, Governor Deukmejian suggested that the insurance industry, business leaders and the Legislature convene to draft a proposal for mandatory earthquake insurance coverage in at-risk areas of California.[2] The Governor's recommendation for an earthquake hazard insurance system is based on the same concept of flood hazard zones used by the federal government. Communities with designated Flood Hazard Zones are required to join the National Flood Insurance Program as a condition of eligibility for federal financial assistance, including federally-backed mortgages. In addition, communities are required to adopt land-use controls in flood prone areas.[3] A requirement to purchase earthquake insurance in concert with community mitigation measures in at-risk areas would support the common objectives of insurers and government in identifying and reducing risk. Improved earth science information would be indispensable in efforts to delineate the at-risk areas.

---

1 U.S. Geological Survey and the California Department of Insurance. *Workshop on Earthquake Risk: Information Needs of the Insurance Industry.* Proceedings of conference in Albuquerque, New Mexico, September 13-15, 1988.

2 Governor's State of the State Address. Sacramento, California. January 9, 1990.

3 Camerer, Colin F. and Howard Kunreuther. "Decision Processes for Low Probability Events: Policy Implications." *Journal of Policy Analysis and Management.* Volume 8, number 4. Fall 1989. Homeowners located in designated Flood Hazard Zones must purchase flood insurance as a condition of receiving a federally-backed mortgage.

Collapse of a residence in Los Gatos during the 1989 Loma Prieta earthquake. The "cripple walls" of this old wood-frame house were unable to withstand the level of ground shaking experienced at 14 miles from the epicenter. Recognition of potential seismic hazards and appropriate retrofitting could have greatly reduced losses. *Photo from Earthquake Engineering Research Institute.*

Collapsed residence in the Santa Cruz Mountains which is situated on the head of a landslide caused by the 1989 Loma Prieta earthquake. Geological investigations prior to construction may have revealed evidence of previous landslides, and informed the owner of potential risks at the site. *Photo from Earthquake Engineering Research Institute.*

CHAPTER FOUR—LOCAL GOVERNMENTS AND PROPERTY OWNERS

Local government and property owners have common interests in seismic hazard information. Both local government and property owners must be concerned with community development, health and safety considerations, and relative property values and uses. In addition, property owners are subject to land-use regulations and building standards imposed by local government. Finally, local governments must, by state law, (1) prepare safety elements for their General Plans which reflect seismic hazard issues of identification and mitigation, (2) address development in fault rupture zones, and (3) make use of seismic hazard information as part of the environmental review process. Both state and local programs prepare information for use by local governments in protecting public safety and reducing losses to property as a result of geological hazards.

Two programs administered by the California Department of Conservation, Division of Mines and Geology, provide geological hazard information for planning purposes.

- Since 1972, following the 1971 San Fernando earthquake, fault rupture hazard information has been provided by the DMG to assist local government in preventing construction for human occupancy across active faults. The Alquist-Priolo Special Studies Zone program has generated more than 400 maps detailing fault rupture hazards throughout California. Special studies zones are delineated by the State Geologist for use by local planning and building officials.
- In 1984, following landslides in the Baldwin Hills in 1980, the Landslide Hazard Identification Program was initiated to identify and delineate areas subject to the dangers of rapid slope failures such as debris flows and mudslides. The landslide program has since produced approximately 20 maps of landslide susceptibility.

In addition to these statewide efforts, several communities have initiated activities to identify local geological hazards. The most notable of these efforts is the San Francisco Bay area map series developed by the Association of Bay Area Governments over the past ten years.

This chapter reviews the current and anticipated uses for seismic hazard information by local governments and property owners. The first section covers local government uses of seismic hazard information, including the findings of recent research and results from interviews conducted with planning and building officials in various localities. The next part discusses property owner uses of geological hazards information as revealed by several important studies in California. The implications of these data on the design of an urban seismic hazards mapping program are included in the summary and conclusions.

LOCAL GOVERNMENTS

As discussed in Chapter Two, local governments generally use seismic hazard information in planning and building department functions. To a lesser extent, geohazard data is used in emergency response planning. The opportunities for using seismic hazard information may be categorized into five groups, as shown in Figure 4.1, and are discussed as follows.

Preparing development studies and plans:

Circulation or transportation studies and plans
Community facility and utility inventories and plans
Environmental impact assessments and reports
Land-use and open space inventories and plans
Land subdivision lot layouts
Multihazard risk analyses and reduction plans
Redevlopment plans (pre-and post-earthquake))
Seismic and public safety plans

Designing and building safe structures:

Building strengthening or retrofitting
Critical facility siting and design
Engineering, geologic, and seismologic reports
Public facility and utility reconstruction or relocation
Reconstruction after earthquakes
Repair of dams
Site-specific investigations and hazard evaluations

Discouraging new or removing existing hazardous development:

Capital improvements expenditures
Cost of nonsubsidized insurance
Disclosure of hazards to real estate buyers
Financial incentives and disincentives
Policies of private lenders
Posted warnings of potential hazards
Public acquisitions of hazardous areas
Public facility and utility service area policies
Public information and education
Public records of hazards (continued)

Figure 4.1. Opportunities for using geologic and seismologic information to reduce earthquake hazards.[1]

1 Excerpted from Ziony, J. I., Editor, *Evaluating Earthquake Hazards in the Los Angeles Region*. U.S. Geological Survey Professional Paper 1360. Menlo Park: U.S. Geological Survey, 1985.

Figure 4.1. Continued.

Removal of unsafe structures
Special assessments and tax credits

Regulating development:

Building and grading ordinances
Design and construction regulations
Hazard zone investigations
Land-use zoning districts and setback requirements
Special hazard reduction ordinances

Preparing for and responding to disasters:

Anticipating damage to critical facilities
Damage inspection, repair, and recovery procedures
Disaster training exercises
Earthquake prediction response plans
Emergency response plans
Monitoring and warning systems
Personal preparedness actions

- **Preparing development studies and plans.** Seismic hazards information is currently used extensively and, generally, as a matter of accepted practice in development studies and planning in California. As a result of state requirements that seismic hazards information be addressed in planning and environmental review processes, local agencies must insure that planning efforts within their jurisdiction consider recent data on seismic hazards.

- **Designing and building safe structures.** Seismic force provisions in the Uniform Building Code are used by local governments to ensure that buildings are designed and built safely. The 1988 provisions specify design based on the seismic zone and site soil characteristics, as well as construction details. Some jurisdictions also require that site-specific geologic or geotechnical reports be prepared that detail the hazard and specify mitigation measures while other jurisdictions specify provisions for reconstruction after an earthquake.

- **Discouraging new or removing existing hazardous development.** This category of measures includes a range of disincentives, improved public information, and removal of unsafe structures. Some of the listed opportunities have been implemented such as disclosure to buyers in special studies zones, posted warnings, and public acquisition of hazardous areas. In addition, essential services buildings (police and fire stations, hospitals, and communications facilities) must, pursuant to State law, conform to special seismic design criteria.

- **Regulating development.** This category of reducing earthquake hazards is probably the most controversial because the development of property is subject to specific requirements that affect the range and type of uses that a site may have. Examples of this measure include Los Angeles' slope grading ordinance and San Jose's hillside ordinance to protect against landslide hazards; hazard zone investigations and setback requirements in Riverside County; and enhanced construction code requirements adopted by Redwood City for development in the "bay muds." These measures are discussed in greater detail under "Exemplary Local Government Programs."

- **Preparing for and responding to disasters.** Emergency response uses of seismic hazard information include use of earthquake scenarios in planning response by fire and police personnel, disaster training exercises conducted by federal, state, and local agencies, and in setting priorities for damage inspection, repair, and recovery.

Recent Research

Several guidebooks and case studies have been prepared which detail methods for using geologic and seismic hazards information in land-use planning.[1] These publications provide planning techniques and examples of measures that have been implemented. A discussion of planning and seismic hazards would be too extensive for this report, so rather than expanding on the universe of available techniques, this section focuses on the uses and problems local governments and planners have regarding seismic hazard information.[2]

In the past several years, three surveys of local planning officials have been conducted that address planning

1 Several examples include: Blair, M.L. and others. *Seismic Safety and Land-use Planning–Selected Examples from the San Francisco Bay Region, California.* U.S. Geological Survey Paper 941-B. Washington, D.C.: U.S. Government Printing Office, 1979.
Bolton, Patricia and others. *Land Use Planning for Earthquake Hazard Mitigation: A Handbook for Planners.* Special Publication 14. Boulder, CO: Natural Hazards Research and Applications Information Center, 1986.
Brown, Robert D. and William J. Kockelman. *Geologic Principles for Prudent Land Use: A Decisionmaker's Guide for the San Francisco Bay Region.* U.S. Geological Survey Professional Paper 946. Washington, D.C.: U.S. Government Printing Office, 1983.
Jaffe, Martin and others. *Reducing Earthquake Risks: A Planner's Guide.* Planning Advisory Service Report Number 364. Washington, D.C.: American Planning Association, October 1981.
William Spangle and Associates. *Geology and Planning: The Portola Valley Experience.* Portola Valley, CA: William Spangle and Associates, 1988.a.
Putting Seismic Safety to Work. Oakland, CA: Bay Area Regional Earthquake Preparedness Project, October 1988.b.

2 In *Geology and Planning: The Portola Valley Experience*, the authors detail seven elements of Portola Valley's program for reducing geological hazards: (1) geological mapping, (2) general plan, (3) zoning regulations, (4) subdivision regulations, (5) site development/grading regulations, (6) building codes and (7) public agency geologist.

and earthquake risk information. The studies include (1) a national survey of communities in 22 states that contain earthquake-prone areas (seismic zones 3 and 4),[1] (2) a survey of planning directors in 118 cities and counties in California,[2] and (3) a survey of local government staff in the San Francisco Bay area to identify applications of products provided by the Association of Bay Area Governments.[3]

National Survey Results. This study focused on local mitigation planning response to earthquake hazards in 22 states, including California. The study received 207 responses from all 22 states but only the analysis of the 85 responses from California is discussed in this report. Approximately 83 percent of the California respondents were planning personnel, 9 percent city managers, and 7 percent building officials, city engineers and emergency planners.

A majority of survey respondents indicated that earthquake hazards are given a low to very low priority in California (60 percent) and only 17 percent consider earthquake hazards a high or very high priority. Nonetheless, nearly 60 percent of the responding communities have six or more earthquake mitigation measures. Building design and construction measures were considered highly effective by 70 percent of the respondents while measures for planning and regulating development were considered highly effective by only 33 percent. In terms of planning resources spent on earthquake-related problems, 74 percent spend less than one staff hour per week and 79 percent indicated that less than one percent of the planning department budget is allocated to earthquake problems.

Respondents indicated that inter-organizational contacts with state level agencies were much greater than contacts with federal agencies such as the U.S. Geological Survey, Federal Emergency Management Agency, and the U.S. Army Corps of Engineers and approximately as frequent as their contacts with regional agencies, city/county agencies, and private consultants. Respondents also indicated that state level agencies were much more responsive to local government needs and problems (69 percent) than any federal (50 percent or less), regional (64 percent), or city/county agency (65 percent), and second only to the responsiveness of private consultants (76 percent).

Finally, when asked what obstacles there were to local mitigation response, respondents felt that lack of state or federal financial support was most serious (49 percent) followed by conservative political culture (44 percent), opposition by real estate and development interests (41 percent) and other less important obstacles. Of the other possible responses, the lack of adequate maps delineating earthquake hazard areas was only considered to be a serious obstacle by 20 percent, indicating that the information sources are generally considered adequate. What is lacking, according to the respondents, is financial and political support for mitigation measures.

Statewide Survey. This survey sought the responses of planning directors in 118 cities and counties in California to identify current planning practices and problems associated with earthquake risk information. Of 105 responses, 52 percent consider seismic hazards to be a *moderate problem* in their jurisdiction while approximately 25 percent consider it a *serious problem.* The most serious hazards were reported to be ground shaking, liquefaction, landslides, and subsidence, respectively. More than 80 percent consider their earthquake data to be somewhat accurate to very accurate and 69 percent consider it generally to be extremely useful. Nearly 90 percent of the jurisdiction's General Plans contain seismic hazard maps. Areal information in the respondents' General Plans primarily delineates hazards of ground shaking (68 percent), liquefaction (54 percent), landslides (45 percent), ground ruptures (31 percent), and subsidence (30 percent). Respondents indicated that seismic hazard information's most important uses are building code enforcement, environmental impact assessment, comprehensive planning, and emergency planning, respectively. Seismic hazard information should address both project-by-project reviews and long-range comprehensive planning, according to the survey. The seismic hazard information that is most lacking is surface geology (91 percent), estimated damage from seismic hazards (51 percent), condition of existing structures (43 percent), and probabilities and intensities of potential seismic events (39 percent). Information which is least lacking is landslide and liquefaction potential (26 percent) and fault locations (12 percent). Finally, similar to responses in the national survey, state government is perceived to be more helpful than federal or local government, and equal to the perceived helpfulness of private consultants.

Association of Bay Area Governments Survey. The ABAG surveyed San Francisco Bay area local governments in 1986 to identify past applications of ABAG products and potential needs. Respondents ranked fault proximity, disrupted roads and power, water supply problems, and weak soils as the most important earthquake-related hazards. According to the survey, ABAG map

1 Berke, Philip and Suzanne Wilhite. *Local Mitigation Planning Response to Earthquake Hazards: Results of a National Survey.* College Station, TX: Texas A&M University, Hazard Reduction and Recovery Center, May 1988.
2 French, Steven P. and Deborah Harmon. "Current Land Use Planning for Seismic Safety in California." Unpublished manuscript. San Luis Obispo, CA, 7 May 1982.
3 Association of Bay Area Governments. *Results of a Survey of Local Governments Use of Earthquake Information.* Oakland, CA: Association of Bay Area Governments, October 1986.

products are used in developing safety elements in General Plans, as background information, and in public information and disclosure programs. It is not clear whether these products are used to specifically set or implement seismic safety policy within the local jurisdictions. Local agencies indicated that priorities for seismic hazard mapping activities should focus on nontechnical text for decision makers, model ordinances, assessments of community risk, and improving the map scale. In particular, nontechnical text and community risk information is perceived to have the greatest direct impact. Respondents also indicated to ABAG staff that they were more interested in the relative risk for smaller geographic areas, such as cities, and were skeptical of numeric loss estimates, like those provided in the ABAG maps.

Interviews with Planning and Building Departments

During the course of this feasibility study, project staff conducted a series of interviews with local planning and building department officials. We spoke with planning and building department staff representing 12 jurisdictions. Personnel from other local agency departments (such as fire, police, emergency services, and public works) participated in some of the interviews. The informal discussions were conducted using an interview questionnaire as a means of focussing the discussion and assuring consistency in the results. We selected the agencies to interview based on the recency of the jurisdiction's seismic safety element (generally prepared in 1985 or later) and the geographic and population diversity of jurisdictions. As indicated in Figure 4.2, the respondents represent jurisdictions located throughout California comprising various sizes and types of organizations.

Interview Responses. The interviewees indicated that they use seismic hazard information in both planning and building department functions. The products used include maps detailing landslides, liquefaction zones, shaking areas, and Alquist-Priolo Special Studies Zones, and geotechnical reports prepared by consultants. The sources of data are the U.S. Geological Survey, DMG, private consultants, and various others. Development approval, plan checking, disclosure to title holders, and further geotechnical investigations are some of the uses of this information.

When asked what type of improved or more detailed seismic hazard information would be most useful, interviewees indicated data on shaking, building provisions related to ground response, liquefaction, landslides, and fault rupture. This information could be used for existing purposes such as development approval and plan checking, triggering special site investigations, emergency planning, and excluding certain facility types from hazardous areas. According to the respondents, improved information should be at a map scale of 1:24,000 or larger. The maps should depict (1) susceptibility of land to specific hazards without regard to particular earthquake sources or (2) the relative hazard posed by cumulative earthquake sources. Earthquake scenarios were the least favored form of seismic hazard information. In addition, respondents generally felt that probabilities would not be helpful in planning maps other than as documentation for planners and building officials. Finally, interviewees currently prefer the map format over digital files, although several agencies anticipate having or using a geographic information system in the future.

Local government respondents indicated that the most useful geohazard information would be:

Ground shaking susceptibility	6
Building measures	4
Liquefaction potential	4
Landslide potential	3
Fault rupture potential and proximity to faults	2

Our discussions with local officials revealed that mapped seismic hazards information should be nontechnical and oriented towards specific applications rather than general depictions of hazards or geological conditions. This was expressed in several responses requesting information to "tailor construction to ground response areas," develop "building parameters and suitability zones" and "design control over critical facilities," and meet a "need for information which translates ground motion into measures." In addition, some respondents suggested that hazard zones could trigger a requirement for a site-specific investigation in the same way that an Alquist-Priolo Special Studies Zone requires geologic reports in areas of potential surface fault rupture. Another official suggested that design criteria could be developed for hazard zones which are more rigorous than non-zone areas. These criteria could be relaxed by the findings of a site-specific report. The experience drawn from the Association of Bay Area Governments' seismic hazards mapping program may be useful in illuminating practical uses for improved information.

The ABAG has carried out an extensive effort in mapping the ground shaking hazard in the San Francisco Bay area. In our interviews with San Francisco Bay area officials, however, we found few uses for the ABAG's products beyond increasing awareness of seismic hazards. Interviewees indicated that the ABAG maps were not at a useful scale or did not provide effective guidance for

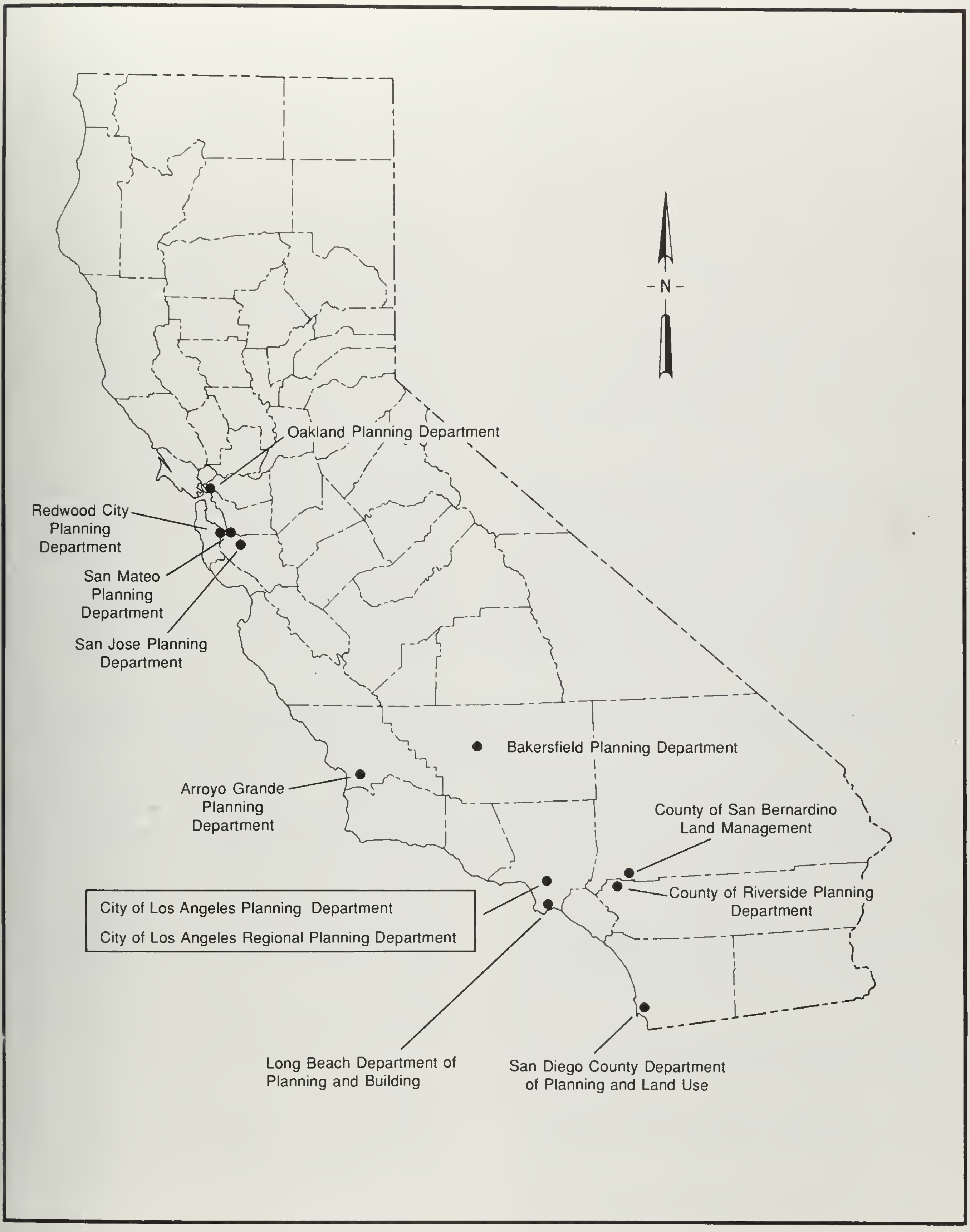


Figure 4.2. Local government agencies surveyed regarding uses of seismic hazard information.

planning. Even if the map scale could be improved, it is not evident, nor are any guidelines given, how a map which depicts the "cumulative damage potential expressed as expected damage discounted to present value" can be used for land-use planning. What land-use policies or standards would be necessary in a very high damage potential zone (5.1-6.0 percent) that would not be needed in a high damage potential zone (4.1-5.0 percent)? In general, planners do not have the professional background or time to translate the ABAG-mapped potential losses into effective land-use policy. We conclude that improved or more detailed seismic hazard data must be applications-oriented to be effective.

Exemplary Local Government Programs

In the course of our discussions with local officials, we examined three hazard mitigation programs that have been recognized for using mapped geological hazards information in an exemplary fashion.[1] The programs are located in Redwood City, Riverside County, and San Jose.

Redwood City Building Division–Redwood Shores Ordinance. In 1974, the Redwood City Council adopted an ordinance to supplement the city's building standards for seismic forces. The enhanced standards apply to bay mud areas within the city and were developed by an engineering consultant to the city. The standards, which have been consistently more stringent than the Uniform Building Code, specify foundation design, lateral force design provisions, foundation systems to resist settlement, reinforcement and redundancy in structural members. In addition, a soils report and geological site investigation are required throughout the bay mud areas.

Riverside County Planning Department–County Fault Hazard Zones and Ground Shaking Zones. Based on responses from the 12 jurisdictions in our review, Riverside County is unique among the other local agencies in its regulation of hazardous areas. First, the Planning Department retains considerable authority for seismic hazard reduction whereas in other jurisdictions, this authority resides largely within the Building Department. The source of Riverside County's seismic hazard policies is the 1984 safety element of the General Plan.

Second, the County requires geological reports (with subsurface trenching) in Alquist-Priolo Special Studies Zones, County Fault Hazard Zones (other fault zones not mapped by the State's program but which are known to the County Geologist), and within 150 feet of a potentially active fault, as defined by the County's seismic-geologic maps. In addition, Riverside County applies the Alquist-Priolo Act not only to residences but to a broad range of structures including "retail stores, theaters, manufacturing buildings, and public service structures, such as civic centers, hospitals and schools, clubhouses, churches and recreation buildings."[2] Thus, the County broadly implements the requirements of the State Alquist-Priolo Special Studies Zone Act.

Third, Riverside County uses five general ground shaking zones (I, II, III, IV, and V) which are divided into five geological characteristics (A, B, C, D, and E). The resulting 25 subzones determine the land-use suitability of four types of facilities–Critical, Essential, Normal-High Risk, and Normal-Low Risk–as shown in Figure 4.3. The less suitable a site is for a proposed project, the greater the burden is on the developer to demonstrate the safety of the site, mitigate the site hazards, and/or enhance the earthquake-resisting design of the project. These zones are indentified on maps and referenced to a land-use suitability matrix detailing the suitability of the four facility types within each of the 25 ground shaking subzones. These materials are available for inspection by builders, land developers, and prospective property purchasers at the Planning Department. The Riverside County approach provides specific guidelines for regulating development in hazardous areas in a straightforward way, while reserving significant regulatory powers for the County Planning Department.

San Jose–Nonurban Hillside Designation. In the 1970s, San Jose experienced extensive landsliding in the northeast quadrant of the city, resulting in damage to residences and associated infrastructure. As a consequence of these landslides, San Jose purchased properties in damaged areas and revised their general plan in 1975 to include a nonurban hillside designation. As a result, San Jose requires site investigation in the hillside areas and specifies reduced densities in areas above the 15 percent slope line to reduce loss of life and damage to property as well as limit the liability exposure of the city. In addition, urban services are not provided above the 15 percent slope line. City planning staff indicate that the hillside designation also supports the city's efforts in reserving "greenline" areas for recreation and open space.

PROPERTY OWNERS

A number of studies have been conducted regarding the use of geohazards information by private parties such as individuals, banks, and real estate agents. In this section, we report the general findings of these studies as well as

1 Many other examples of exemplary seismic safety programs are reported in William Spangle and Associates. *Putting Seismic Safety Policies to Work*. Oakland, CA: Bay Area Regional Earthquake Preparedness Project, October 1988.

2 Ordinance No. 547. An Ordinance of the County of Riverside Implementing the Alquist-Priolo Special Studies Zone Act. As amended, July 1, 1988.

LAND USES	LAND-USE SUITABILITY IN GROUND SHAKING ZONES																								
	IA	IB	IC	ID	IE	IIA	IIB	IIC	IID	IIE	IIIA	IIIB	IIIC	IIID	IIIE	IVA	IVB	IVC	IVD	IVE	VA	VB	VC	VD	VE
CRITICAL Nuclear relatedsystems; major dates explosives or hazardous materials manufacturing, handling, or storage; hospitals and other emergency medical facilities.	PS	PS	PS	PS	R	U	R	U	R	R	R	R	U	R	R	R	R	U	R	R	R	R	R	R	R
ESSENTIAL Police, fire and communications systems; Emergency Operations Centers (EOCs); electrical power inter-tie systems; power plants; small dams; utility substations; sewage treatment plants; waterworks; local gas and electric distribution lines; major highways, bridges and tunnels; ambulance services; public assembly with capacity of 300 or more; schools.	PS	PS	PS	PS	U	U	U	PS	R	R	R	R	U	R	R	U	R	U	R	R	R	R	R	R	R
NORMAL - HIGH RISK Multi-family residential of 100 or more units; major commercial including large shopping centers; office buildings; large hotels; health care clinics and convalescent homes; heavy industry; gas stations.	S	S	S	S	PS	S	S	S	PS	U	PS	PS	S	U	U	PS	U	PS	U	R	U	U	PS	U	R
NORMAL - LOW RISK Single-family residential; multi-family of 100 or less units; small scale commercial; small hotels, motels; light industrial; warehousing.	S	S	S	S	S	S	S	S	S	PS	S	PS	S	PS	U	S	PS	S	U	U	PS	PS	S	U	U

EXPLANATION:

S	Generally Suitable	- Expected levels of ground shaking are generally less or equal to design levels as defined in the Uniform Building Code (UBC).
PS	Provisionally Suitable	- Expected levels of ground shaking generally exceed design levels as defined in the UBC by a factor ranging from approximately 1 to 2.
U	Generally Unsuitable	- Expected levels of ground shaking generally exceed design levels as defined in the UBC by a factor ranging from approximately 2 to 5.
R	Restricted	- Expected levels of ground shaking generally exceed design levels as defined in the UBC by a factor in excess of 5.

NOTE: This table is intended for general planning purposes. The definitions which relate ground shaking levels to the UBC and development suitability apply strictly only to the Normal Risk Land Uses. Suitability of the Essential and Critical Categories reflects strong considerations for community safety and disaster recovery. Detailed site investigations and engineering studies may be necessary for certain structures and uses particularly in the Critical and Essential categories.

Figure 4.3. Riverside County Planning Department matrix of land-use suitability in ground shaking zones.[1]

conversations we have had with major property owner organizations.

Research Findings

There have been several attempts to discern the responsiveness of property owners to seismic hazard information in California. Three of the studies cited here measure responsiveness by differences in behavior between areas within Alquist-Priolo Special Studies Zones and areas outside of these zones. As noted above, these zones delineate areas of potential surface fault rupture and, by association, damaging ground motions. A 1989 study tested the relationship between *objective* seismic risk–as measured by expected intensities, distance from a special studies zone, and distance from the San Andreas fault–and individuals' earthquake insurance purchase decisions. The results of these studies paint a complex picture of property owner response to seismic risk information.

Real Estate Agents and Special Studies Zones Disclosure (Palm, 1981). This survey, conducted in the city of Berkeley and in central Contra Costa County, found that there was "little measurable buyer response" to special studies zones by home purchasers. In general, home buy-

1 Riverside County. *Riverside County Comprehensive General Plan: Environmental Hazards and Resources Element.* Adopted by the Board of Supervisors of Riverside County, Resolution 84-77. As amended December 22, 1987.

ers consider distance from an active earthquake fault to be a much less important factor than investment potential, price, beauty of area, views, or other factors. Distance from an earthquake source rated about equal to access to public transportation and location out of a flood plain, the least important factors for in-zone buyers. Even among buyers who knew that their home was within a special studies zone, 50 percent indicated a belief that people who live in the zones are not any more susceptible to losses than those outside of the zones. This finding suggests that home buyers are aware of the extensive reach of damaging ground motion from an earthquake. Finally, the survey found that home buyers who were aware of their location within a special studies zone were more likely to purchase earthquake insurance. Indeed, in-zone buyers' responses showed that inquiring about earthquake insurance (41 percent) and purchasing earthquake insurance (24 percent) were the most common mitigation measures adopted. Other mitigation measures such as acquisition of emergency supplies, emergency planning, and structural and nonstructural retrofitting were adopted by 20 percent or less of the in-zone respondents. In summary, these findings suggest that special studies zones do not, by themselves, motivate home buyers to significantly alter their purchase decisions. In-zone home buyers, however, are more likely to inquire about and buy earthquake insurance as a means of hedging seismic risk.

Home Mortgage Lenders, Real Property Appraisers and Earthquake Hazards (Palm and others, 1983). This study reviewed the decision-making by lenders and real estate appraisers in southern and northern California and in the Puget Sound area of Washington. The responses of lenders are important because seismic hazards affect the vulnerability of a lender's mortgage portfolio to losses. This study found that 68 percent of the lenders evaluating commercial property loans and 76 percent evaluating residential loans do not consider seismic risk. Most lenders rank earthquakes low as a possible cause of mortgage default, following unemployment, divorce, house fire, and flooding. The few lenders who do consider seismic risk and make loan modifications as a result avoid issuing loans in high risk areas or require earthquake insurance as a condition of the loan.

One reason lenders do not generally consider seismic risk is perhaps because mortgage portfolios usually are composed of properties spread over a large geographic area. Thus, the risk of earthquake damage is spread over many mortgages, reducing the probability of a catastrophic number of defaults. In addition, lending is a competitive activity. Loan conditions and modifications based on seismic hazards could result in a loss of market share. Lenders may also be unwilling to add to the cost of lending when the probability of extensive earthquake damage appears remote.

A Test of the Expected Utility Model–Evidence from Earthquake Risks (Brookshire and others, 1985). This study attempted to estimate the significance that special studies zones have on housing prices in the Los Angeles and San Francisco Bay areas using housing market sales data for more than 10,000 transactions in 1972 (prior to zoning) and 1978. The study found that houses outside of special studies zones were valued more, on average, than houses within these zones. In addition, the model coefficient associated with special studies zones increased in magnitude and in terms of statistical significance in both communities between 1972 and 1978, indicating an increasing influence of special studies zones on property value over that period. On average, location in a special studies zone results in a 5.6 percent lower price in Los Angeles and 3.3 percent lower house price in San Francisco. The authors indicate that these price differentials correspond remarkably to the relative expected probabilities of major damaging earthquakes in the Los Angeles and San Francisco areas–a Los Angeles event is surmised to be approximately twice as likely as a San Francisco event.[1] The study concludes that the disclosure requirement for properties within special studies zones is effective in eliciting self-insuring behavior.

Does a Mandated Insurance Offer Affect the Propensity to Purchase Earthquake Insurance? (Palm, 1989). This study surveyed approximately 2,500 owner-occupied households in Contra Costa, Los Angeles, San Bernardino, and Santa Clara counties in 1989 to determine whether the state-mandated earthquake insurance offer has affected the demand for earthquake insurance. Relevant to this study, the survey results indicated that there is little, if any, relationship between insurance purchase and *objective* seismic risk–as measured by predicted shaking intensity, distance from an active surface fault zone, and distance from the San Andreas fault. In other words, adverse selection (purchase of earthquake insurance by those at greatest risk) does not appear to be a factor in earthquake insurance. The study concludes that earthquake insurance purchase is primarily related to the homeowner's beliefs regarding the likelihood of a major damaging earthquake and expected damage. Although the study does not draw any conclusions regarding how these beliefs are formed, public information and disclosure, presumably, influence a homeowner's perceptions of earthquake risk.

1 According to the Working Group on California Earthquake Probabilities (U.S. Geological Survey, 1988), the probability of a major earthquake in the San Francisco Bay region is about 50%, while the combined probability of a major earthquake on the San Jacinto or San Andreas fault in southern California is about 80%.

Discussions with Property Owning Organizations

During the course of this study, we spoke with officials who represent or are keenly aware of property owner interest in seismic hazard information, including the Building Office Managers' Association, California Departments of General Services and Veterans Affairs, and the Southern California Earthquake Preparedness Project. These discussions revealed that seismic hazard data mapped at a regional scale (1:24,000) is not widely desired by property owners. Building managers are more interested in reliable site-specific information. The two state agencies–General Services and Veterans Affairs–do not currently use geohazards information even though both manage the disposition of billions of dollars of property. General Services is the property manager of most state-owned and leased property that is occupied by state agencies. Veterans Affairs operates the Cal-Vet Home Loan Program which makes home and farm loans to California veterans. General Services personnel further indicate that earthquake insurance is not purchased due to its high cost, the State's practice of self-insurance, and the availability of federal disaster assistance. In the event of a major damaging earthquake, according to General Services, the cost for repair of damage that has occurred to a specific state building for the first time is covered by FEMA. This is one-time coverage only, and the structure would subsequently require earthquake insurance unless waived by FEMA because of an unusually high premium. In addition, the State's significant annual budget resources can provide self-insurance funds to pay for some damage to state facilities.

Veterans Affairs, on the other hand, has provided disaster insurance (covering flood and earthquake damage) protection for participants in the Cal-Vet program since 1973. The program is unique in that the deductibles and insurance rates are low–$250 per occurrence and $.50 per $1,000 value, respectively–compared to private insurance programs. In addition, participation in the disaster insurance program is a condition of receiving a Cal-Vet loan. The Disaster Indemnity Fund was set up to provide up to $4 million for losses. In addition, a private insurance policy purchased by the department will provide the next $100 million of coverage. Currently, there are approximately 83,000 mortgage contracts with a combined value of $3 billion.

The disaster insurance program provides two benefits: (1) participants receive disaster insurance at a favorable cost, and (2) the budgetary resources of the State are protected against large risks by the first-loss self-insurance fund and the private insurance policy. Veterans Affairs does not use seismic hazards information to either estimate potential losses or set risk-based rates. The department indicates that because properties are located throughout the state, the probability of catastrophic insurance claims is small. The department estimates that claims from the 1987 Whittier earthquake totalled approximately $3 million. Claims from the 1989 Loma Prieta earthquake are still being processed but may exceed the $4 million first-loss amount.

SUMMARY AND CONCLUSIONS

Local governments have an ongoing need for seismic and geologic hazard information. These data are required for long-term applications such as comprehensive land-use planning and development approvals as well as short-term uses such as current planning and site approvals. Information provided by the Alquist-Priolo Special Studies Zone and the Landslide Hazard Identification and Mapping programs has prompted and supported greater use of geohazards information. Our review indicates that local governments can make use of improved seismic hazard data if it is nontechnical in presentation and applications-oriented. That is, a geological map would not be appropriate, by itself, for planning or building department functions. Local governments are interested in ground shaking, landslides, and liquefaction but desire hazards information that infers policies and practices for safe development and construction. Ideally, seismic hazard mapping would include prescribed practices according to the building type and hazard zone designation. However, development of this type of information would, in fact, be precarious because (1) there is not enough known about vulnerability and seismic hazards to provide precise construction codes, and (2) each locality should have ultimate responsibility for weighing community risks and taking appropriate mitigation measures. It may make more sense for jurisdictions to resolve issues of risk and uncertainty by requiring information which further delineates the hazard.

Several local officials have suggested that special studies be conducted in designated hazard zones, in much the same way special studies are required in Alquist-Priolo Special Studies Zones. In this way, no specific type of construction would be excluded from a hazard zone unless the special study identified conditions which were impossible or impractical to mitigate from an engineering or geotechnical perspective. Developers of a particular site, therefore, would have to weigh the benefits of the project against the costs of mitigating the hazard. In economist's terms, the cost of the hazard would be imputed into the total cost of the project. If disclosure to property purchasers were required, the risk cost would also be likely to be imputed by prospective purchasers into the offer price, resulting in a value which more nearly reflects the cost of developing and operating a property in a hazardous area. Another approach would be to require certain construction standards within hazard zones that could be modified if a special study found the hazard to be benign or mitigable. This approach, however, could result in construction practices which overlook more hazardous conditions and which lend unwarranted confidence to the construction standards. In addition, establishment of threshold standards does not allow a local official sufficient flexibility if subsequent information demonstrates that the standards are inadequate.

As indicated above, property owners (particularly individual owner-occupiers) do make some use of seismic hazards information either through collective property valuation assessments or by inquiring about and purchasing earthquake insurance. Public information about seismic hazards, however, appears to influence the earthquake insurance purchase decisions of an entire community rather than just those located within designated hazard zones or nearby earthquake sources. Enhanced risk information theoretically helps individuals make informed decisions about seismic hazards and property purchases. To be more effective, disclosure of hazards should be made earlier in the purchase process, perhaps when a property is listed for sale or before an offer is presented by a prospective purchaser so that prospective purchasers would be able to compute the value of the seismic risk, before a purchase offer is made, and adjust their bids accordingly.

Residence torn apart by fault rupture during the 1971 San Fernando earthquake. Such occurrences led to the Alquist-Priolo Special Studies Zone Act of 1972, which introduced the concept of *special studies zones* to prevent certain types of development across active faults. *Photo from University of Southern California, Department of Geological Sciences.*

CHAPTER FIVE—PROGRAM AND POLICY IMPLICATIONS

SUMMARY OF FINDINGS

Our discussions with insurers, local government, and property owner organizations document the need for improved seismic hazard data. The type and use of hazard information required, however, vary according to the different purposes served by these groups.

Insurers

Insurers favor any reasonable improvements in seismological, geological and engineering knowledge which can be directly related to the earthquake insurance context. Ideally, insurers desire data which describes the probabilities of earthquake occurrence and dollar loss damage ratios for various types of structures by zip code. Insurers could then simply multiply the probability of occurrence by the loss ratio for a given building type to get an expected loss ratio. This product would be multiplied by the replacement value of the property to calculate an expected loss of the structure. All expected losses would be summed to provide an expected loss for the portfolio. Insurers would then have an actuarially-sound basis for estimating exposure and setting risk-based rates.

Given the large uncertainties associated with earthquake occurrence and associated damage, however, insurers prefer information which realistically depicts the risk associated with ground shaking, fault rupture, and ground failure.[1] Several industry officials indicated in informal discussions that hazards represented in terms of relative risk would be preferred to data which is unjustifiably quantitative or for which there are large uncertainties.

Local Government

Based on our discussions with local officials and a review of seismic safety elements in local general plans, local governments can also use improved and more detailed seismic hazards information to support planning and building department functions. In general, local jurisdictions desire delineation of potential problems such as areas of ground shaking, landslides, and liquefaction. Probabilities associated with potential problems are *not* considered useful except as reference information for local officials. Of the standard scales used in the U.S. Geological Survey map compilations, local governments generally prefer information at the 1:24,000 scale. At this scale, maps are not sufficiently detailed for site-specific determinations but the data can be used to focus local officials' attention on hazardous areas. Maps depicting high-hazard zones can be used by local officials to prompt the preparation of site-specific geotechnical reports by developers, thus resolving the uncertainties inherent in mapped information. In addition, general design, engineering, and land-use provisions governing facilities to be located within hazard zones can be developed by jurisdictions. Finally, local governments generally desire State participation in seismic hazards mapping efforts because the State is viewed as being responsive to their needs. Local governments also look to the State to provide policy guidance on earthquake hazard matters and may welcome state requirements for hazard compliance because their arguments for adopting a mitigation measure are supported by the advice of a disinterested and authoritative body.

Property Owners

Property owners, on the other hand, must be considered indirect users of hazard information because they are not likely to use maps directly. Nonetheless, improved seismic hazard information which is presented in a simple, straightforward fashion does appear to influence building siting and purchase decisions. Studies have shown that property values and earthquake insurance inquiries appear to be affected by the presence of Alquist-Priolo Special Studies Zones. The series of major earthquakes beginning in 1983 and the mandated offer of earthquake insurance initiated in 1985 have contributed to a trend towards higher earthquake insurance purchase rates. Thus, seismic risk information, if widely disseminated, does appear to influence risk behavior among property owners. However, even if property owners did not take advantage of *existing* geohazards information, they could benefit from improved information if it becomes part of the property purchase and insurance decision-making process.

PROGRAM IMPLICATIONS

Our review of seismic hazards information needs of insurers, local governments, and property owners suggests that a hazard identification program should map areas of ground shaking, landslides, and liquefaction.[2] We have

1 Insurers' desire for fault rupture information suggests that insurers either (1) are not fully aware of the California's Alquist-Priolo maps, (2) seek fault rupture information nationwide and responded accordingly, or (3) wish any new fault rupture data. At any rate, fault rupture data are already available in California through the Alquist-Priolo Special Studies Zone program.

2 Our findings are not without precedent. In a 1972 report of the Joint Committee on Seismic Safety, California Legislature, *The San Fernando Earthquake of February 9, 1971 and Public Policy*, are recommendations for geological information, seismic mapping, and public reports on subdivisions. In *Earthquake Hazards Reduction: Issues for an Implementation Plan*, the President's Office of Science and Technology Policy recommended in 1978 that adequate, detailed earthquake hazards information and guidelines for its use be prepared for planners and decision-makers of local units of government. More recently, a 1989 workshop on Loss-Reduction Provisions of a National Earthquake Insurance Program conducted for the Federal Emergency Management Agency and the Federal Insurance Administration identified four land-use planning measures which address zoning for liquefaction, landslides, and faulting.

observed that the maps produced by the Association of Bay Area Governments have limited use by local officials in identifying especially hazardous areas. In part, this is due to the small scale of the maps (1:125,000).

We believe, however, that a principal reason the ABAG maps are not useful in decision-making is because they contain a large number of graduations in shaking and damage levels which are difficult for planners and building officials to interpret. More important, however, is the fact that these maps contain no policy guidance for local officials. A nontechnical local official, therefore, is left with an abundance of information–classifications of shaking intensity and expected damage to various types of structures–but no means of translating the data into effective planning or building policy.

The experience from the Alquist-Priolo Special Studies Zone program has demonstrated that distinctive hazard zones are more effective policy tools because (1) the most hazardous areas are clearly outlined, (2) required practices within the zones (such as setbacks) are specified, and (3) uncertainties in risk information are resolved by the required geotechnical studies. In addition, the special studies requirement does not lock in a set of development and construction standards. Thus, a community's planning and building standards for earthquake hazards may remain flexible to reflect improvements in earthquake hazards information and engineering methods. Finally, the community's earthquake standards are also better able to reflect the community's unique values and attitudes towards acceptable risk.

An effective hazard zoning program would therefore map ground shaking, landslides, and liquefaction areas with an emphasis on high-hazard zone identification. Ground shaking hazard zones could be based on the presence of soft clay (Uniform Building Code soil types S3 and S4).[1] Appropriate definitions for high-hazard areas of landsliding and liquefaction would require development but would be identical in concept by attempting to focus attention on the most hazardous conditions.[2] To meet the information needs of insurers, the geographic boundaries of hazard zones could be tabulated into the corresponding zip codes. Maps would be developed at the 1:24,000 scale in urban areas and at a smaller scale within unincorporated areas (perhaps 1:100,000). More important than the mapping efforts would be the prescribed measures of such a program–local governments prefer information which is readily translatable to planning and building policy. For this reason, the Alquist-Priolo Special Studies Zone program is a useful prototype for a more expansive earthquake hazard identification model.

Daughter of A-P–Seismic Hazards Studies Zones

A Seismic Hazards Studies Zones (SHSZ) program modelled after the Alquist-Priolo Special Studies Zone program would require:

- Delineation of SHSZs by the Division of Mines and Geology for areas highly susceptible to ground shaking, landsliding, and liquefaction,
- Inclusion of SHSZs in General Plans and adoption of land-use suitability measures by local government to regulate development within SHSZs,
- Preparation and submission of site-specific reports to local officials along with all applications for development approval and building permits for real property within a delineated SHSZ, and
- Disclosure of the existence of a SHSZ encompassing real property at the time the property is offered for sale in advertisements and sales notices.

The proposed SHSZ program would differ from the Alquist-Priolo approach in that (1) hazard zones would include a greater range of hazards, (2) local governments would be required to develop measures to address land-use suitability in hazardous areas, (3) site-specific reports would be required on *all* properties to be developed, without the current statutory exemptions for single-family dwellings in fault rupture zones, and (4) disclosure would be required *at the time real property is offered for sale*, rather than just prior to closing escrow, as is the current practice.

Delineation of a broader range of hazards than fault rupture is suggested by the responses from insurers and local officials as well as recent experience from the 1989 Loma Prieta earthquake, which demonstrated impressive examples of shaking amplification in San Francisco's Marina district, landsliding in the Santa Cruz Mountains, and liquefaction in San Francisco and Oakland (Earthquake Engineering Research Institute, 1990).

Local governments would be required to develop measures for addressing land-use suitability to reduce uncer-

1 S4 soil type was added in the 1988 version to address concerns over areas of potential shaking amplification that characterized the 1985 Michoacan earthquake which devastated Mexico City. The UBC describes S4 as "(a) soil profile containing more than 40 feet of soft clay."

2 The State's Landslide Hazard Identification Program in the California Department of Conservation, Division of Mines and Geology, maps areas of relative landslide and debris flow susceptibility. The maps depict four levels of susceptibility, from least susceptible to most susceptible, and do not address seismically-induced landslides. In addition, the most susceptible areas in one part of the state are not directly comparable to the most susceptible areas in another region. Thus, in theory, a low susceptibility area in one map may be more susceptible than a highly susceptible area in another map. Liquefaction mapping is not currently undertaken by the State.

tainty in the development and building process and to involve local officials directly in hazardous areas policy setting. Local officials could adopt modified versions of methods identified earlier in this report–specifically, practices of Riverside County, Redwood City, and San Jose. Integral to the local government hazards mitigation process is the requirement that site-specific studies be conducted on all properties within a SHSZ at the time a development or structure is proposed. The information generated from these reports would assure local officials of the actual conditions within a SHSZ and would continue to expand the local official's knowledge base of earthquake hazards. The cost of geotechnical reports is small (approximately $1,500 to $4,000) relative to the cost of developing most sites in California and would assure local officials, the property owner, and future property owners that the site has been safely developed.

Disclosure of SHSZ conditions early in the real property sale process is important for prospective buyers so that they can consider the earthquake hazard and risk associated with a property. Informed buyers would then be able to set a value on a property based on their assessment of the risk and their attitudes towards earthquake risk. In addition, early disclosure would support local government planning objectives because the potential uses of a property located within a SHSZ may be limited by local officials. In addition, insurers could develop earthquake insurance rates, using data produced by the program, based on the implicit seismic risk. Thus, prospective property owners would be advised of the earthquake hazard, and made aware of possible limitations of the local planning and building departments and possible higher insurance rates. A disclosure requirement might contain the following language:

> "Whenever real property is listed for sale by a person who is acting as an agent for a seller of real property, or the seller if he is acting without an agent, the seller shall disclose in advertisements, sales notices, property descriptions and any materials made available to prospective purchasers the fact that the property is within a delineated Seismic Hazards Studies Zone. Prospective purchasers shall be advised in the disclosure that uses of the property within delineated Seismic Hazards Studies Zones may be limited by local planning and building officials and that earthquake insurance rates may differ, depending on the actual site conditions. Prospective buyers shall be advised in the disclosure to investigate these conditions prior to completing a purchase of real property located within a delineated Seismic Hazards Studies Zone."

Other Hazard Zone Measures

In addition to program elements inspired by the Alquist-Priolo Special Studies Zone program, there are other hazard zone measures which could enhance the effectiveness of an SHSZ program in reducing risks in especially hazardous areas. These measures could include:

- *Condition eligibility for future State disaster assistance on adoption of mitigation planning and measures by local government.* Under federal provisions for flood hazard zones, communities are required to take specific measures to reduce flood hazards as a condition of receiving federal disaster assistance. Also, communities receiving federal disaster assistance following an earthquake must develop an earthquake hazard mitigation plan with specific risk reduction measures as a condition of receiving future federal disaster assistance. Following the 1987 Whittier and 1989 Loma Prieta earthquakes, the State provided hundreds of millions of dollars in disaster assistance and reconstruction loans. In a parallel fashion, the State could require mitigation measures and/or the purchase of earthquake insurance for those facilities receiving State disaster assistance. The State could also require, in delineated Seismic hazard zones, that other forms of State financial assistance to local government be conditioned on mitigation measures and/or the purchase of earthquake insurance. State requirements to reduce or insure unusual earthquake risks would result in reduced risk to property owners and the State's financial resources.

- *Provisions for special property tax assessments or fees in SHSZs.* Special assessments or fees could be levied to support adequate engineering review for compliance and the enhanced emergency response needs and the greater risk posed to infrastructure as a result of development within these zones.

- *Required adoption of reconstruction ordinances.* Reconstruction ordinances could be adopted specifying allowable building types and criteria for properties located within SHSZs following a major earthquake. This type of ordinance could regulate the reconstruction of certain type buildings by (1) direct regulation (prohibiting specified types), (2) establishing financial disincentives such as a schedule of building permit fees that discourage unsuitable uses or buildings or potential earthquake impact fees, or (3) imposing stringent design and construction requirements for rebuilding in SHSZs.

- *Risk-based earthquake insurance rates.* Insurers could be required to set earthquake insurance rates which reflect the enhanced risk of properties located within SHSZs. This measure would lend support to the planning objective of reducing a community's earthquake risk by providing a further financial disincentive for locating within hazardous areas.

- *Claims-reporting by insurance companies.* Estimates of actual earthquake losses to property are considered proprietary insurance company information. The public, however, has a legitimate scientific and public policy interest in understanding the nature and extent of earthquake losses. If private insurance company claims data were made publicly available, loss estimation technology could be improved, resulting in more effective earthquake hazard mitigation.

POLICY CONSIDERATIONS

The decision for the State to undertake greater efforts towards earthquake hazard identification and mitigation, as suggested above, is a policy issue. Generally, policy makers may approach earthquake hazards in one of three ways: (1) do nothing, (2) improve the effectiveness of existing efforts, or (3) undertake new initiatives. The recent northern California earthquake demonstrates the need for additional hazard mitigation. Because of the widespread geotechnical effects of this earthquake, the need for seismic hazard mapping which delineates hazardous areas of ground shaking, landslides, and liquefaction is well demonstrated. This type of hazard identification, however, is not a part of existing State programs. The public policy problem of seismic hazard identification, therefore, is a State issue, and raises questions concerning the consequences of adopting a hazard reduction program, the level of effort justified, and funding considerations. We have identified for discussion below three possible consequences of hazard zoning which directly affect the interests of the parties studied in this report, including inverse condemnation (local officials), changes in property values (property owners), and adverse selection (insurers).

State Interests in Hazard Mitigation

State efforts to identify and assess seismic hazards are concentrated in two programs mentioned previously: the Alquist-Priolo Special Studies Zones and Landslide Hazard Identification, both under the purview of the State Geologist in the California Department of Conservation, Division of Mines and Geology. There are at least four reasons why the State should be involved in hazard identification:

- *State Interests.* Losses from geological hazards are borne by the State (1) when State property is damaged, (2) in the form of assistance to local governments, businesses, and property owners, and (3) in the form of reduced tax revenues. Thus, although local governments set planning and building policy, the State has a direct interest in reducing seismic hazards.

- *Efficiency.* The State currently has the programmatic structure in place to identify geologic hazards in the California Department of Conservation, Division of Mines and Geology. It is more cost-efficient for these resources to be consolidated into one organization at the state level than to have multiple local government programs.

- *State Coordination.* Natural hazards do not respect jurisdictional boundaries. In addition, hazard mitigation activities by one jurisdiction (or the lack thereof) affect the risk faced by another. For example, failure to mitigate landslide hazards in one community may affect the transportation and communication links to another community. The State, therefore, can assure coordination between jurisdictions by providing consistent standards for mitigating hazards.

- *Local Assistance.* Local government views the State as responsive to their needs, and looks toward the State for policy guidance and support for local programs.

Inverse Condemnation

Inverse condemnation occurs when government activities adversely affect the value or uses of private property so as to constitute a taking without just compensation. Inverse condemnation typically includes instances where the direct effects of a government activity (accidental flooding of property) results in a taking (settlement of structures) without just compensation. Theoretically, inverse condemnation could result when local planning decisions affect the use and/or values of a property. Designating a hazard zone would not, in all likelihood, constitute a taking. The application of new standards limiting the development or use of property based on a hazard zone designation may be considered a taking. The legitimate public policy purposes of protecting the health and safety of a community, however, are likely to prevail over arguments in favor of inverse condemnation.[1]

In the *First English Evangelical Church of Glendale v. County of Los Angeles* court case, the plaintiffs argued that Los Angeles County's ordinance to disallow the rebuilding of facilities damaged in a flood hazard zone owned by the First English Evangelical Church consti-

1 Personal communication with Thomas Blake, Deputy Attorney General, California Department of Justice, January 17, 1990.

tuted a taking without just compensation. The U.S. Supreme Court held that a landowner is entitled to compensation when a court finds there has been an unconstitutional regulatory taking. The Supreme Court then remanded the decision to the California state courts for a determination whether the county's action in this case amounted to an unconstitutional taking. The state appellate court found that the county's ordinance was a valid exercise of police power and was therefore not an unconstitutional taking. Thus, no compensation was awarded. On this basis, it appears that government's exercise of police power to protect the health and safety of the public through hazard zoning and building regulations would not be considered an unconstitutional taking. Thus, inverse condemnation claims based on geological hazards zoning are unlikely to prevail.

Even if the doctrine of inverse condemnation is successfully applied to regulation of natural hazards in California, it would not be sufficient justification to relieve local officials of their responsibility to protect public safety through zoning. In fact, if public officials knew or should have known that land-use regulation was necessary in hazardous areas, the jurisdiction may still be liable for damages. In addition, even if the courts do not find the jurisdiction liable, considerable legal and court expenses are likely to be incurred by the jurisdiction. Thus, local officials may be criticized if they do act but they are certain to be criticized if they don't. The difference is that jurisdictions which actively work to mitigate earthquake hazards through hazard zone regulations, however, are supported by the public policy purpose of protecting public safety while those choosing not to mitigate are acting defensively.

Changes in Property Values as a Result of SHSZs

Property uses and values may change as a result of SHSZ designation. Property located within a SHSZ may have a diminished market value because of buyers' recognition of enhanced risk and limitations on the potential uses of the site (e.g. cantilevered decks may be prohibited in SHSZs by local officials). Although the current property owners may suffer a loss in value when a SHSZ property is sold, the property would then more nearly reflect the value of the cost posed by the earthquake risk, in the same way that other property characteristics such as zoning, school districts, and tax assessments are imputed in the market value.

If hazard zones were not delineated, current property holders might not be harmed if they were to sell the property prior to a damaging earthquake. Prospective purchasers or future property owners would be harmed if a subsequent earthquake results in damage that could have been mitigated by the use of hazard zoning. Thus, providing no information does not reduce the hazard, it simply shifts the cost burden to others. The loss in property value resulting from a hazard zone designation would be theoretically equal to the discounted future earthquake losses if prospective purchasers accurately assess the potential earthquake losses and reflect these values in bidding on property. If, however, the supply of developable properties decreases after hazard zones are established, all current property holders will experience an increase in value. It is also possible that a hazard zone designation may have little effect on property values. In any case, such a designation simply requires that the earthquake risk, a source of potential loss in value, be reflected along with other property characteristics.

Finally, a current property holder in a hazard zone may in fact be harmed more by the lack of information than by the potential loss in property values as a result of hazard zoning. The additional risk information associated with a hazard zone could persuade property owners to take mitigating action that they would not have otherwise undertaken. Consequently, losses could be avoided and the potential loss in property value caused by a hazard zone designation would be offset by the value of loss-reducing improvements.

One condition of an efficient free market system is that good information be widely available so that consumers may differentiate between goods. To support an efficient market for real property, seismic risk information should be made available at the time the property is offered for sale rather than at the closing of escrow, as is the current practice. In this way, prospective purchasers are able to factor in the seismic risk prior to bidding on the property in the same way that other known conditions–such as age of the electrical system, quality of area schools, and the presence of flood hazards–are imputed to the value of a property.

Adverse Selection

Adverse selection is a term used to describe certain insurance purchasing behavior by individuals. According to theory, individuals who face the least risk will have less propensity to buy insurance than those at greatest risk. While this result is not wholly inconsistent with the purposes of insurance,[1] insurers desire a large pool of risks over which to distribute losses. Some earthquake insurers are concerned that earthquake risks are subject to adverse selection, thus limiting the pool over which to

1 Insurance provides a means of distributing risk from those unable to sustain the potential loss by themselves to those who can, collectively, sustain the loss.

spread risk to a small group of high risks (U.S. Senate Committee on Commerce, Science and Transportation, 1987). While this may be true on a national level (Californians purchase earthquake insurance more than, say, Texans), recent research does not support this theory on a county level.[1] It is not clear whether designation of new high-hazard zones would elicit a change in earthquake insurance purchasing behavior. Adverse selection, however, is not a persuasive argument against providing improved earthquake hazard information to the property owners, who currently bear the majority of the risk, or to local government, which is bound to protect the health and safety of its constituents. The insurance industry, perhaps in concert with government, may need to undertake marketing activities to broaden participation in earthquake insurance by property owners.

1 In Risa Palm's 1989 study, the presence of an Alquist-Priolo Special Studies Zone, distance from an active fault, or expected earthquake intensity, does not correlate with the individual's decision to purchase earthquake insurance. Rather, the decision is based on the individual's attitude toward earthquake risk.

Considerations for Level of Effort Required

A SHSZ program should be undertaken at a level of effort so that its products may be useful in mitigating damage from future earthquakes. Although we cannot yet predict earthquakes, we can expect, based on historical averages, that earthquakes in California will occur approximately every 18 years for M7 and greater, and every 2 years for M6 and greater.

Not all of these events, however, will occur in densely populated areas. Some damaging earthquakes will occur in areas so sparse that a general hazard identification program would provide few, if any, benefits. To be effective, therefore, a SHSZ program should delineate the most hazardous areas in the most populous parts of the state within the next 2 to 18 years. Accordingly, we believe that a probabilistic assessment of fault activity should be used in conjunction with population estimates and population growth rates to establish appropriate staffing and funding levels for a SHSZ program.

Structural collapse of an apartment complex in San Francisco's Marina District during the 1989 Loma Prieta earthquake. While liquefaction is a hazard in the district, the duration of strong shaking was too short to induce seriously damaging liquefaction. Most damage resulted from enhanced ground shaking triggered by the underlying soft sediments. *Photo from Earthquake Engineering Research Institute.*

CHAPTER SIX—RECOMMENDED METHODS AND DATA FOR HAZARD ASSESSMENT

INTRODUCTION

In order to identify appropriate methods for producing improved seismic hazard information products, current methods of assessing ground shaking, liquefaction, and seismically-induced landslides over large geographic areas were reviewed. We also evaluated the adequacy and accessibility of existing geologic data in California's major urban areas, since it would not be economically feasible to implement a program of hazard assessment based entirely on the acquisition of new geologic information. The recommendations in this chapter draw primarily upon recent comprehensive review papers by the National Research Council, the American Society of Civil Engineers, and Professional Papers of the United States Geological Survey. The principal conclusion is that appropriate methods, data, and technology already exist that can permit delineation of SHSZs in California, and provide the insurance industry with improved data for evaluation of exposure.

Seismic Hazard Studies Zones identify areas where enhanced ground shaking, liquefaction, and seismically-induced landslides are likely to occur. Delineation of these zones can be based on simplified methods of hazard assessment, while the more sophisticated and costly methods of hazard assessment can be used for site-specific determinations of hazard. This chapter presents the methods and data proposed for a program which delineates SHSZs and provides more detailed information for use in evaluating seismic risk.

GENERAL METHODS

Enhanced ground shaking, liquefaction, and seismically-induced slope failure are hazards that primarily depend on the response of earth materials to earthquake shaking. Consequently, their assessment is a two-step process. The first step involves assessing the shaking an area can expect to experience from future earthquakes in a time frame to be of concern to society. The second step involves assessing the relative tendency of geologic materials throughout the area to cause the specific hazards during seismic shaking. The former assesses the "opportunity" for the hazard, while the latter assesses the land's "susceptibility" to the hazard. Combining the two yields the "potential" for the occurrence of the hazard. This general approach underlies each of the recommended methodologies for delineating SHSZs.

Conventional probabilistic seismic hazard analysis or hybrid methods (National Research Council, 1988) can be used to determine expected incident ground motions over large geographic areas, unaffected by topography and soil conditions at the site. Accounting for both source and path effects, this approach is now being considered for the generation of national seismic zone maps (U.S. Geological Survey, 1989) in the forthcoming 1991 addition of the Uniform Building Code (UBC). These methods are also incorporated into several of the earthquake loss models used by the insurance industry, as discussed in Chapter 3. Figure 6.1 shows a probabilistic shaking hazard map for the contiguous U.S. As the first step in assessing shaking related hazards, a comprehensive probabilistic seismic hazard analysis should be undertaken to determine the severity of ground motions that can be expected throughout California.

Enhanced Ground Shaking Hazard

Ground shaking from earthquakes affects large geographic areas and accounts for nearly all earthquake losses. Several factors determine the severity of ground shaking at a given location. They can be characterized as source effects (size of the earthquake, length of fault rupture, amount of fault displacement, type of faulting, and character of vibrational energy release), path effects (the attenuation of ground motion with distance from the causative fault), and site effects (either attenuation or amplified shaking caused by topography, basin structure, and resonance of near surface soil deposits). Site effects are primarily responsible for enhanced ground shaking hazard at the site.

When assessing ground shaking hazard, it is convenient to separate the factors that control regional ground motions (source and path effects) from those that modify these incident ground motions at the site (site effects). In this manner, enhanced ground shaking can be viewed as a collateral hazard that is triggered by specific geologic conditions that are mappable at a site, similar to liquefaction and slope failure.

Outside the earthquake rupture zone or epicentral area, at distances where the ground motion is normally attenuated, site effects are commonly the cause of anomalously high ground shaking. They can be accounted for by preparation of maps indicating the relative susceptibility of geologic material to enhanced ground shaking. Certain soil deposits, such as thick soft clays, are known to sig-

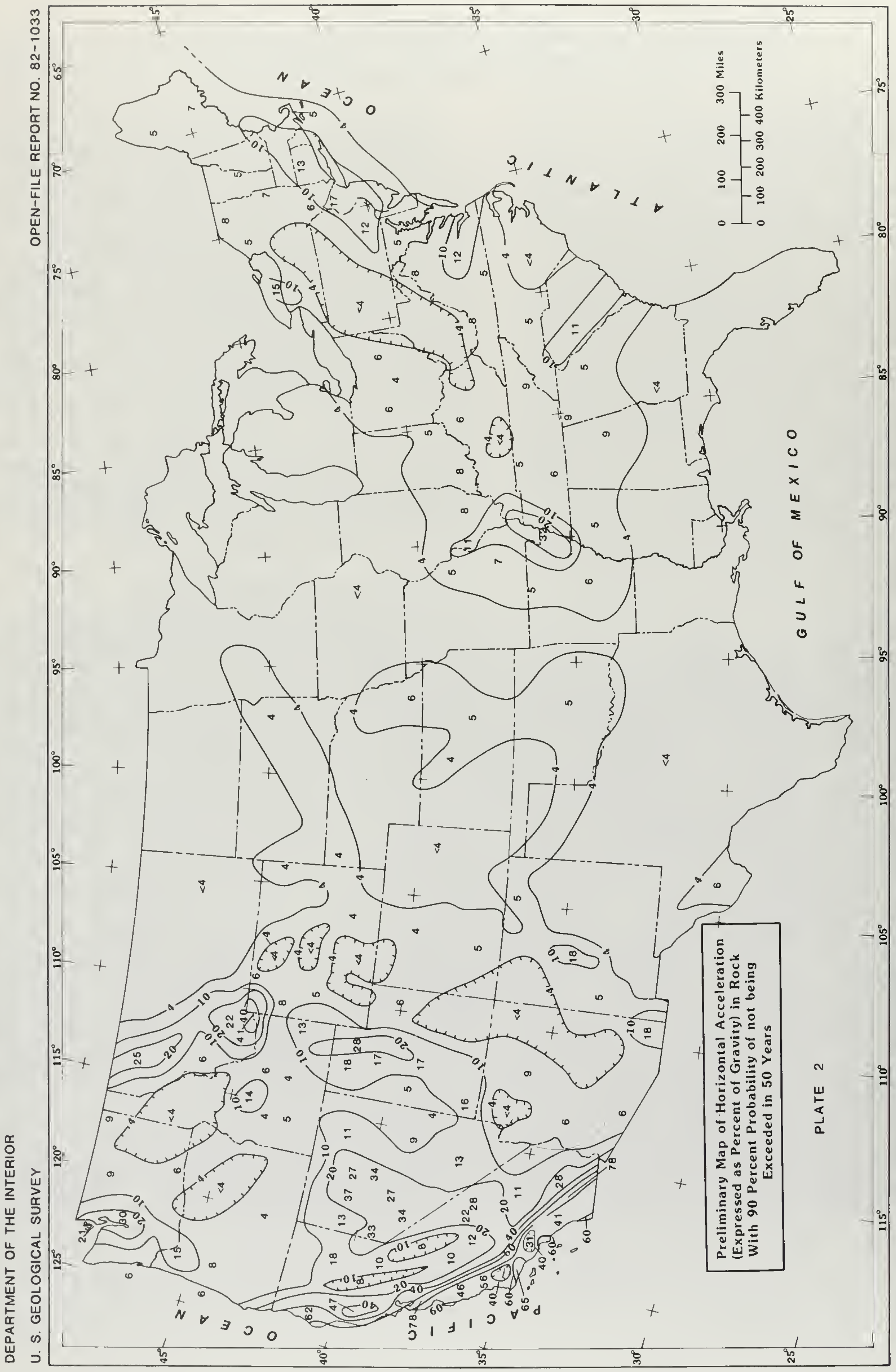


Figure 6.1. Probabilistic shaking hazard map for the contiguous U.S. (USGS, 1982).

nificantly amplify ground shaking. Recent examples of this phenomenon include earthquakes affecting Mexico City (1985), Armenia (1988), and most recently the San Francisco Bay region (1989). Recognition of discrete areas based on the varying response of soils to earthquake shaking has permitted zoning of Mexico City for shaking hazard (Figure 6.2). Mexico has incorporated the zoning into its building code, with special provisions developed for each zone (Inglesias, 1989).

In the United States, the UBC recognizes four soil types in the determination of lateral force requirements for structural design (Table 6.1). Buildings constructed over thick soft clays must be built to resist twice the base shear as those constructed over stiff soils or rock. Unlike the Mexican code, the UBC soil types and associated design coefficients are determined by site-specific geotechnical investigations rather than inferred from mapped information. Mapped areas corresponding to the most severe enhanced shaking hazard can be effectively linked to existing code provisions, however, by delineating areas in which S3 and S4 soil types are known to occur.

Identifying and mapping geologic conditions likely to contain S3 and S4 soil can be based on analysis of existing bore hole data, and to a lesser degree, on existing surficial geologic maps. The reliability of hazard zones that are delineated in this manner is directly related to the spatial density of bore-hole coverage.

Table 6.1. Uniform Building Code site coefficients.[1]

Type	Description	Factor
S1	A soil profile with either: a) A rock-like material characterized by a shear-wave velocity greater than 2,500 feet per second or by other suitable means of classification, or b) Stiff or dense soil condition where the depth is fewer than 200 feet.	1.0
S2	A soil profile with dense or stiff soil conditions, where the soil depth exceeds 200 feet.	1.2
S3	A soil profile 40 feet or more in depth containing more than 20 feet of soft to medium stiff clay but not more than 40 feet of soft clay.	1.5
S4	A soil profile containing more than 40 feet of soft clay.	2.0

[1] This factor is a multiplier in the standard formula for determination of base shear, the total lateral design force at the base of a structure. (International Conference of Building Officials, 1988.)

Other methods that have been proposed for assessing enhanced ground shaking hazard include mapping relative ground response either by calculation of theoretical response factors based on detailed soil and sediment properties, or determination of empirical response factors by monitoring of weak-motion response from small earthquakes and microtremors (American Society of Civil Engineers, 1988). While having the advantage of providing more quantitative site response factors as a function of frequency, application of these methods for zonation purposes is not recommended at this time. Theoretical approaches suffer from the requirement to accurately describe the input site characteristics over large regions to be mapped, while adequately accounting for all physical processes contributing to site response.

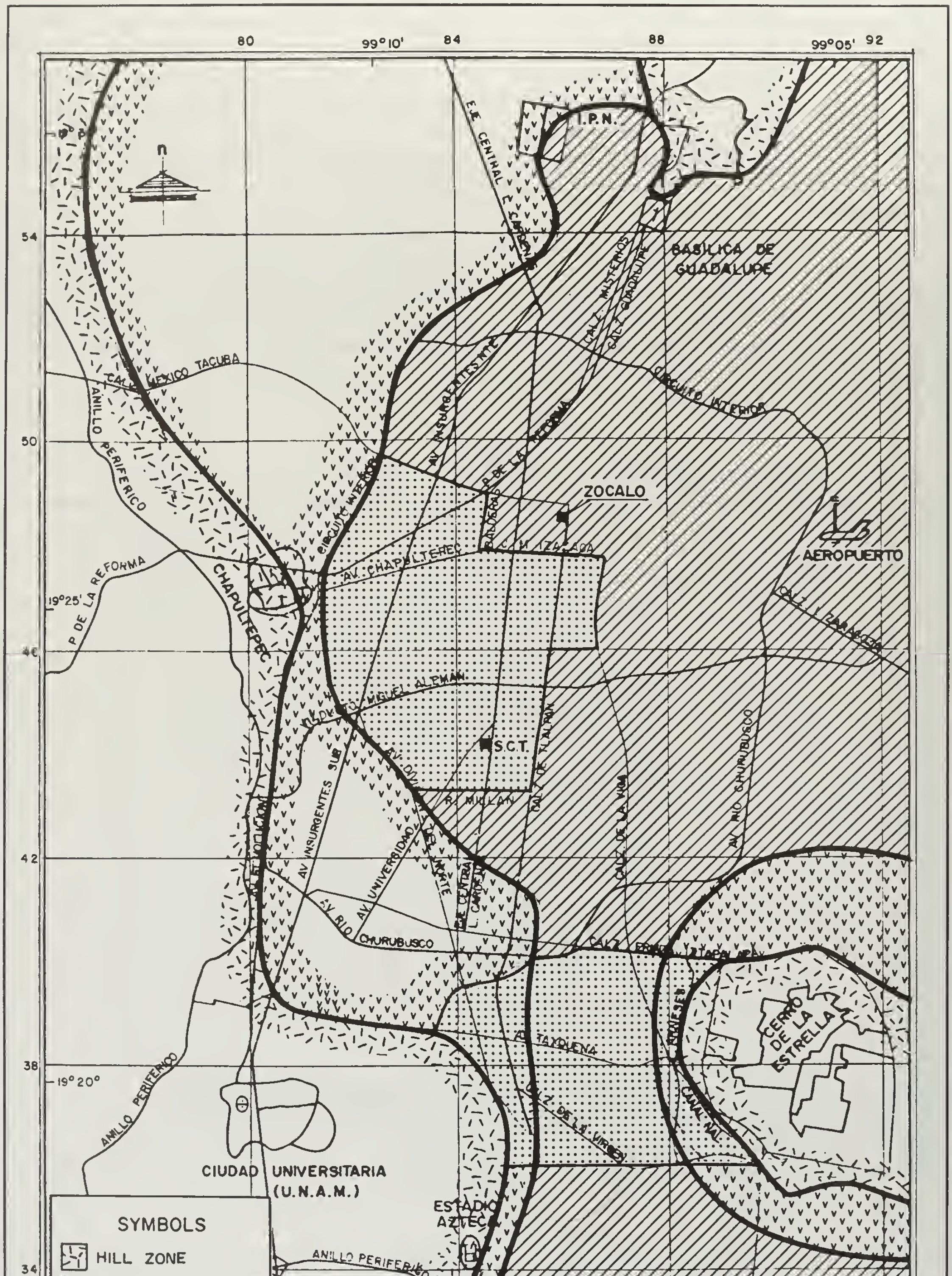


Figure 6.2. Seismic zonation map of Mexico City (Inglesias, 1989).

Because the utility of proposed methods has yet to be adequately demonstrated, the soil characteristic method as used in the UBC is recommended for the assessment of enhanced ground shaking hazard. Research should continue, however, on theoretical and empirical methods because they have the potential to identify new, as yet unrecognized, hazardous site conditions.

Loss reduction measures for areas of enhanced shaking hazard primarily include use of the lateral force requirements of the UBC. Other possible measures that could be implemented if SHSZs were designated include reduced densities of development, restrictions on construction of high-risk structures, and more stringent design and construction requirements based on the expected level of shaking at the site. Special ordinances have been developed for some communities that supplement the UBC requirements in high hazard areas, such as those imposed in Redwood City for construction on the bay muds of San Francisco Bay (William Spangle and Associates, 1988b).

Liquefaction Hazard

Liquefaction occurs when loose, water-saturated granular soil compacts during seismic shaking. Since water is less compressible than sediments, pore pressure increases, forcing sediment particles apart and causing the soil to liquefy. Under these conditions, the ground deforms by lateral movement down gentle slopes (lateral spreading), fluid-like movement of sand and water (flow failure), and reduced bearing capacity that can cause structures to settle into the ground (Table 6.2). While there are sophisticated methods of laboratory analysis for site-specific assessments, areas having geologic conditions favorable to liquefaction can be screened by using simple geologic criteria such as the age and type of sediments, and depth to groundwater (National Research Council, 1985).

More reliable analyses combine simple geotechnical criteria such as grain size and penetration resistance with geological criteria. Areas susceptible to liquefaction can be delineated by the occurrence of geologically young deposits characterized by the abundance of silt and sand with minimal concentrations of gravel and clay, in regions where the water table is within 50 feet of the ground surface. These conditions can be determined by using existing geologic maps and available bore-hole data as has been demonstrated for the Los Angeles and San Diego areas (U. S. Geological Survey, 1985a; Woodward-Clyde Consultants, 1982). Resulting maps show the relative susceptibility of geologic materials to liquefaction. In some localities in California, however, such maps would not accurately indicate the potential for liquefaction to occur, because some areas may never experience the strong ground shaking necessary to trigger liquefaction in a time frame to be of concern.

Combining regional ground shaking with liquefaction susceptibility maps delineates areas of liquefaction potential. Relationships that indicate whether liquefaction is possible have been well established between soil stiffness, as indicated by the standard penetration test, and severity of ground shaking, as determined from peak horizontal ground acceleration (National Research Council, 1985). This approach has been successfully used to evaluate liquefaction potential for different sites in the San Diego area (Woodward-Clyde Consultants, 1986). As with enhanced ground shaking hazard zones, the most hazardous liquefaction areas can be designated as special study zones. These zones can be based on areas of high liquefaction potential.

Methods of reducing liquefaction hazard at the site can be categorized as removal of liquefiable material, soil densification, pore pressure reduction strategies, containment of liquefiable material, and various structural remedies (Table 6.3). The city of San Diego recently adopted a liquefaction ordinance that includes many of these methods of mitigation (Christopherson, 1986; Haley and others, 1985). Many other California communities at risk from liquefaction hazard have no equivalent provisions in place.

Seismically-Induced Landslide Hazard

Landslides, or more generally, slope failures, occur when a mass of earth material, rock, soil, and sediment, moves down slope under the influence of gravity. Volumes of material can range from a few cubic yards to tens of thousands of cubic yards, with movements of a few inches a year to more than 10 miles per hour. While slope failures occur without earthquakes, they are often initiated by ground shaking accompanying earthquakes. The greatest loss of life from slope failure (200,000 lives) accompanied the great 1920 earthquake in Kansu Province, China (Sidel and others, 1985).

Delineation of special study zones for earthquake-induced landslide hazards can be based on steepness of slope, weakness of material, and severity of expected shaking. The delineation of SHSZs for landslides will require that landslide susceptibility be based on uniform criteria for slope and strength of materials. As for liquefaction, seismically-induced landslide potential incorporates the severity of expected shaking, and can form the basis for delineating SHSZs.

Table 6.2. Structures affected by liquefaction.[1]

Type of Structural Instability	Structures Affected
Loss of bearing capacity	Buried and surface structures
Slope instabilities	Structures built on or at the base of the slope Dam embankments and foundations
Movement of liquefied soil adjacent to topographic depressions	Bridge piers, railway lines, highways, utility lines
Lateral spreading on horizontal ground	Structures, especially with slabs on grade, utility lines, highways, railways
Excess structural buoyancy caused by high subsurface pore pressure	Buried tanks, utility poles
Formation of sink holes from sand blows	Structures built on grade
Increase of lateral stress in liquefied soil	Retaining walls, port structures

[1] National Research Council, 1985.

Table 6.3. Counter measures for liquefaction-prone areas.[1]

1. Removal of susceptible material and replacement with materials of low susceptibility.

2. In-place densification by:
   a) vibrocompaction
   b) compaction piles
   c) dynamic compaction
   d) compaction grout
   e) surcharging

3. Reducing potential for pore pressure buildup by
   a) surface drains
   b) control of water table by dewatering
   c) injection and grouting
   d) admixture stabilization
   e) thermal stabilization

4. Soil reinforcement by:
   a) vibro-replacement stone and sand columns
   b) root piles and soil nailing
   c) other retention structures to contain lateral displacement of soils

5. Structural remedies to resist liquefaction effects:
   a) piles and batter piles
   b) deep foundations or appropriate structural system to accommodate differential ground displacements

[1] National Research Council, 1985.

Wilson and Keefer discuss aerial limits of seismically-triggered sliding for various classes of slides (U.S. Geological Survey, 1985b). This information can be combined with knowledge about the classes of slides most readily triggered by earthquakes, and those posing the greatest threat to public safety, to highlight the most hazardous areas.

Current landslide mitigation programs are based on slope angle, which is a principal criterion in most existing grading ordinances as well as ordinances that regulate the density of development in hillside areas. Grading ordinances typically include specifications for cut and fill, including slope angles, limitations on compaction and lift thickness, and other engineering parameters. Such ordinances have saved hundreds of millions of dollars over the past few decades, and have estimated benefit/cost ratios as high as 110:1 (Leighton, 1976). While not specifically aimed at earthquake effects, these measures have reduced the hazards of seismically-induced slope failure by increasing slope stability. There are many other landslide mitigation strategies that can be broadly grouped as either slope stabilization or protection against slope failure (Table 6.4). Many of these techniques go beyond current grading ordinances, and can be effectively applied in SHSZs.

WHY DESIGNATE SHSZs?

With the existence of building codes, liquefaction ordinances, and grading ordinances, of what value is the designation of SHSZs? First, local codes and ordinances

Table 6.4. Counter measures for landslide-prone areas (Wold and Jochim,1989).

A. Slides and Slumps

1. Increase drainage by: a) surface methods such as ditches, regrading, and surface sealing, b) subsurface methods including horizontal drains, vertical drains/wells, trench drains/interceptors, cut-off drains/counterforts, drainage tunnels or galleries, blanket drains, electro-osmosis, blasting, and surface barriers.

2. Excavation or regrading of slope: a) total removal of landslide mass, b) regrading of slope, c) excavation to unload the upper part of landslide, or d) excavation and replacement of the landslide toe with other materials.

3. Placement of retaining structures: a) retaining walls, b) piles, c) buttresses and counterweight fills, d) tie rods and anchors, or e) rock bolts/anchors/dowels.

4. Planting of vegetation.

5. Soil hardening: a) chemical treatment, b) freezing, c) thermal treatment, or d) grouting.

B. Debris Flows and Debris Avalanches

1. Source-area stabilization: a) check dams, and b) revegetation.

2. Energy dissipation and flow control: a) check dams, b) deflection walls, c) debris basins, d) debris fences, e) deflection dams, and f) channelization.

3. Direct protection: a) Impact spreading walls, b) stem walls, and c) vegetation barriers.

C. Rockfalls

1. Stabilization: a) excavation, b) benching, c) scaling and trimming, d) rock bolts/anchors/dowels, e) chains and cables, f) anchored mesh nets, g) shotcrete, h) buttresses, and i) dentition.

2. Protection: a) rock-trap ditches, b) catch nets and fences, c) catch walls, and d) rock sheds or tunnels.

usually operate on a site by site, case by case basis, without providing a framework to apply loss reduction measures on a geographic basis. SHSZs, on the other hand, designate potentially hazardous areas within which a variety of loss reduction measures can be applied well in advance of development permits. Such measures can affect decisions on whether and how best to develop in the site selection stage, when costs of alternatives are lowest. Second, SHSZs highlight the most hazardous areas within which countermeasures can go beyond local ordinances to include many of those listed in Tables 6.2 - 6.4. Third, SHSZs can eventually provide the insurance industry a means of improving estimates of exposure and adjusting rates or deductibles accordingly. Linking the increased costs of construction and insurance to a common zone would provide incentives to develop outside high-hazard zones, lending support to loss reduction land-use policies. Finally, designation of SHSZs would induce many communities in California that have no hazard ordinances to develop and implement them.[1]

ADEQUACY OF EXISTING GEOLOGIC DATA

We identified sources of geologic information and reviewed their availability and adequacy for the purpose of assessing ground shaking, liquefaction, and landslide hazards. The data are grouped into subsurface and other geologic data. Our principal conclusion is that the data are abundant, and that the acquisition of new data would not be a significant element of a program to delineate SHSZs.

Subsurface Geologic Data

During the course of this study an effort was mounted to identify sources of geologic bore-hole data, characterize and evaluate the usefulness of the information content, and develop a means of indexing these data geographically so that an evaluation of their spatial density could be made. Three types of investigations generally involve the drilling and logging of bore-holes: hydrologic, petroleum exploration, and engineering. Early agricultural land use and water needs, the search for hydrocarbons, followed by intense growth and urbanization in California have resulted in hundreds of thousands of subsurface geologic borings. Our evaluation concentrated on data acquired over the past few decades.

The principal sources of water well data are the California Department of Water Resources, the California Water Quality Control Board, the California Department of Health Services, and the Metropolitan Water District of southern California. These agencies are either repositories of water well data, or have accumulated extensive files of well log information in order to fulfill their mandates. Together these data account for nearly 40,000 wells located in the Los Angeles, San Francisco, and San Diego metropolitan areas. Water well data generally include geologic descriptions of the material encountered, which can be used to identify and extrapolate characteristics of subsurface materials over large areas. It also includes information on the depth to water table, which is required for assessing liquefaction hazard.

THUMS, a consortium of major oil companies, and the City of Long Beach's Department of Oil Properties are the primary sources of oil and gas wells drilled throughout the Los Angeles basin. These wells contain valuable information on the geologic properties of subsurface rocks and sediments, and are unique because they provide information at depths far greater than those reached by water wells or engineering borings.

By far the most useful bore-hole information for assessing seismic shaking hazards comes from engineering borings. These borings are conducted to evaluate foundation stability for construction, and are often used to assess seismic stability of the site. The principal sources of this information are the California Department of Transportation, the Los Angeles Department of Public Works, and about a dozen major geotechnical consulting firms. Together, these sources account for nearly 70,000 borings in the Los Angeles, San Francisco, and San Diego metropolitan areas.

While engineering bore-hole data were not originally acquired to assess regional earthquake hazards, they were acquired at considerable cost spread over several decades, and are generally available. They would cost at least $100 million to acquire if they were not already available. The general availability of these data is, in fact, what makes the delineation of SHSZs technically and economically feasible.

Table 6.5 identifies the number of project sites containing bore-hole information, and provides an estimate of spatial density for the San Diego, Los Angeles, and San Francisco metropolitan areas.

Other Geologic Data

There exists a wealth of other geologic information for California's principal metropolitan areas that is useful for assessing ground shaking hazards. This includes basic geologic and geophysical maps produced by DMG and the USGS. DMG has mapped the entire state at a

1 William Spangle and Associates (1988a) present an informative discussion on the roles of codes, ordinances, and geologic hazard information in loss reduction, based on experience in the San Francisco Bay community of Portola Valley.

Table 6.5. Existing engineering and water well bore-hole sites in Los Angeles, San Francisco, and San Diego.

Location of Projects	Number of Projects	Density of Projects (per square mile)
Los Angeles:	48,000	
Downtown		52
Surrounding area		16
San Francisco:	22,000	
Downtown		76
Surrounding area		13
San Diego:	31,000	
Downtown		68
Surrounding area		11

scale of 1:250,000, and is now mapping portions of the state at 1:100,000 with over six times the detail. Other maps include a special series of large-scale geologic maps (1:24,000) covering portions of Los Angeles and Ventura counties which is being published by the Dibblee Foundation, and special large-scale hazard maps which are being prepared by DMG, the USGS, and private consulting firms under contract with local jurisdictions or private companies. For example, liquefaction susceptibility maps have been recently completed for the city of San Diego (1986) and San Jose is currently underway. Additionally, the National Flood Insurance Program's flood zone maps are available, which show boundaries of high water stands. These maps could be used to help delineate the boundaries of geologically-recent flood deposits, which are of particular relevance to liquefaction. Thousands of site-specific hazard reports are currently on file with DMG. These include site reports for schools and hospitals under the requirement of Title 24 of the California Administrative Code, environmental impact reports

Collapse of the Nueva Leon apartment buildings caused by the 1985 Mexico City earthquake. The soft lake bed deposits amplified ground motions to damaging levels at distances exceeding 200 miles from the epicenter. *Photo from Earthquake Engineering Research Institute.*

for seismically sensitive developments that fall under the requirements of the California Environmental Quality Act, and special investigations required for critical facilities such as dams and power plants.

Finally, of particular value to slope stability analysis are aerial photography and remote sensing data. Computer processing of digital terrain models and NASA's multi-spectral thematic mapper simulator data is currently being used to recognize terrain susceptible to slope failure. These techniques could prove valuable in assessing the land susceptibility to other hazards as well.

NEW ANALYSIS TOOLS

It is essential that hazard assessments utilize the new, powerful technologies well suited for analyzing complex physical phenomena over wide geographic areas. This includes geographic information systems, digital image processing systems, and knowledge-based systems technology. These technologies are gaining popularity among local governments, and both anticipated and unexpected benefits are being realized. Such benefits include 1) cost savings in map production and maintenance, 2) more thorough and effective analysis of spatial data, 3) increased effectiveness of map products through greater accessibility and use, and 4) greater inter-agency communication and unification of policies, procedures, and data utilization practices (Thompson, 1989).

CONCLUSIONS

The scientific methods, technology, and data exist to systematically evaluate susceptibility to earthquake shaking-related hazards, and to delineate zones of high hazard potential. The existence of critical subsurface data upon which hazard assessments will be based is fortuitous; otherwise, such a program would be cost-prohibitive. Instead, further use of this information will effectively increase the benefits from capital investments made decades ago for other purposes. What is needed is a well organized program to translate this information into seismic hazard policy for effective land-use, construction, and insurance decisions to minimize losses from inevitable future earthquakes in California.

REFERENCES

Alesh, Daniel J., and William J. Petak. The Politics and Economics of Earthquake Hazard Mitigation. Program on Environment and Behavior Monograph #43, Boulder, CO: Institute of Behavioral Science, University of Colorado, 1986, p. 223-234.

Alexander, Maria. A Status Report of City and County Safety Elements. California Division of Mines and Geology. Unpublished manuscript, 1 December 1988, p. 46.

Alfors, John T., John L. Burnett, and Thomas E. Gay, Jr. Urban Geology Master Plan for California: The Nature, Magnitude and Costs of Geologic Hazards in California and Recommendations for their Mitigation. Bulletin 198, Sacramento, CA: California Division of Mines and Geology, 1973, p. 112.

Algermissen, S.T., and Steinbrugge, K.V. Estimation of Earthquake Losses. *In* Proceedings of Conference XIII of the U.S.G.S., 1980. Open-File Report 81-437. Ed. Walter W. Hays, Menlo Park, CA: U.S. Geological Survey, 1981, p. 162 - 163.

All-Industry Research Advisory Council. Catastrophic Losses: How the Insurance System Would Handle Two $7 Billion Hurricanes, Oak Brook, IL: All-Industry Research Advisory Council, November 1986, p. 73.

Allen, Clarence. Geological and Seismological Lessons. *In* The San Fernando Earthquake of February 9, 1971 and Public Policy. Ed. George O. Gates. Special Subcommittee of the Joint Committee on Seismic Safety, California Legislature, July 1972, p. 1-11.

American Management Association, Insurance Division. What's New in Risk Management? New York, NY: American Management Association, Inc., 1959, p. 115.

American Society of Civil Engineers, Earthquake Engineering and Soil Dynamics II - Recent Advances in Ground-Motion Evaluation. American Society of Civil Engineers, Geotechnical Special Publication No. 20, 1988, p. 103-155.

Applied Technology Council. Earthquake Damage Evaluation Data for California. ATC - 13 Ed. Christopher Rojahn, Redwood City, CA: Applied Technology Council, 1985, p. 492.

Arnold, C., R. Eisner, M. Durkin, and D. Whitaker, Occupant Behavior in a Six-Storey Office Building Following Severe Earthquake Damage. *In* Disasters, Volume 6, No. 3. 1982, p. 207-214.

Arnold, Christopher, A.I.A. Earthquake Disaster Prevention Planning in Japan, San Mateo, CA: Building Systems Development, Inc., November 1982, p. 85.

Arrow, Kenneth J. Discounting and Public Investment Criteria. *In* Water Research. Ed. Allan V. Kneese and Stephen C. Smith, Baltimore, MD: Johns Hopkins Press for Resources for the Future, Inc., 1966, p. 13-47.

Association of Bay Area Governments. Results of a Survey of Local Governments' Use of Earthquake Information, Oakland, CA: Association of Bay Area Governments, October 1986, p. 14.

Association of Bay Area Governments. Earthquake Insurance Issues, Oakland, CA: Association of Bay Area Governments, September 1977, p. 14.

Baker, Earl J. Toward an Evaluation of Policy Alternatives Governing Hazard-Zone Land Uses. Natural Hazard Research Working Paper 28, January 1976, p. 73.

Bancroft, Charles–President, California Mutual Insurance Company. Earthquake: not if, but when? and where? *In* Journal of Insurance, Volume XLII, January/February 1982, p. 3-9.

Bates, Thomas F. Transferring Earth Science Information to Decisionmakers. Geological Survey Circular 813, Menlo Park: U.S. Geological Survey, 1979, p. 30.

Baumann, Nancy, and Rod Emmer. Flood Insurance and Community Planning. Natural Hazard Research Working Paper 29, Boulder, CO: Institute of Behavioral Science, University of Colorado, June 1976, p. 84.

Baumol, W. J. On the Social Rate of Discount. *In* American Economic Review, Volume 43, No. 4, September 1968, p. 788-802.

Berke, Philip, and Suzanne Wilhite. Local Mitigation Planning Response to Earthquake Hazards: Results of a National Survey. National Science Foundation Grant Number ECE-8421106, College Station, TX: Hazard Reduction and Recovery Center, Texas A&M University, May 1988, p. 38.

Bernknopf, R.L., R. H. Campbell, D. S. Brookshire, and C. D. Shapiro. A Probabilistic Approach to Landslide Hazard Mapping in Cincinnati, Ohio, with Applications for Economic Evaluation. *In* Bulletin of the Association of Engineering Geologists, Volume XXV, No. 1, 1988, p. 39-56.

Bierman, Harold Jr., and Jerome E. Hass. Capital Budgeting under Uncertainty: A Reformulation. *In* Journal of Finance, Volume XXVIII, No. 1, March 1973, p. 119-129.

Blair, M. L., and W.E. Spangle. William Spangle and Associates. Seismic Safety and Land-use Planning–Selected Examples from California. Geological Survey Professional Paper 941-B, Washington, D.C.: U.S. Government Printing Office, Washington, 1979, p. 82.

Blum, Deborah. Earthquake: California Is Not Prepared. *In* California Journal, August 1987, p. 391-394.

Blundell, D.J., and others. The Guatemala Earthquake: Lessons and Priorities for Earthquake Planning and Relief (Papers from a Symposium of the London Technical Group). *In* Disasters, Volume 1, No. 2, 1977, p. 79-112.

Bolton, Patricia A., S. G. Heikkala, M. M. Green, P. J. May. Land Use Planning for Earthquake Hazard Mitigation: A Handbook for Planners. Special Publication 14, Boulder, CO: Natural Hazards Research and Applications Information Center, 1986, p. 121.

Borcherdt, R., G. Glassmoyer, M. Andrews, and E. Cranswick. Effect of Site Conditions on Ground Motion and Damage. Earthquake Engineering Research Institute Special Supplement Armenia Earthquàke Reconnaissance Report, August 1989.

Bortugno, Ed. Effective Use of Earth Science Information at the Local Governmental Level. BAREPP 85-3, Oakland, CA: Bay Area Regional Earthquake Preparedness Project, June 1985, p. 16.

Brabb, Earl E., and Roger D. Borcherdt. Progress on Seismic Zonation in the San Francisco Bay Region. *In* Geological Survey Circular 807. Ed. E. E. Brabb, Washington, D.C.: U.S. Department of the Interior, p. 91.

Bradley, Stephen P., and Sherwood C. Frey, Jr. Capital Rationing and Discounting in Public Sector Investment Decisions. In Omega: The International Journal of Management Science. Volume 7, No. 1. 1979, p. 77-79.

Brookshire, D.S., W.D. Schulze, and others. Methods Development for Benefit-Cost Analysis of Natural Hazards Information, Laramie, WY: The Institute for Policy Research, October 1983, p. 1.1-7.27.

Brookshire, David S., and others. A Test of the Expected Utility Model: Evidence from Earthquake Risks. *In* Journal of Political Economy, Volume 93, No. 2. 1985, p. 369-389.

Brown, Robert D. , and William J. Kockelman. Geologic Principles for Prudent Land Use. Geological Survey Professional Paper 946, Washington D.C: U.S. Geological Survey, 1983, p. 97.

Brown, William M., III, William J. Kockelman, and Joseph I. Ziony. Future Directions In Evaluating Earthquake Hazards of Southern California, Washington D.C: U.S. Geological Survey, November 1985, p. 421.

California Department of Conservation, Division of Mines and Geology. Landslide Hazard Identification Program Annual Report 1988, Sacramento, CA: California Department of Conservation, 1988, p. 8.

California Department of Insurance. California Earthquake Zoning and Probable Maximum Loss Evaluation Program, Los Angeles, CA: California Department of Insurance, June 1986, p. 44.

California Department of Insurance. California Earthquake Zoning and Maximum Loss Evaluation Program, Los Angeles, CA: California Department of Insurance, June 1987, p. 55.

California Department of Insurance. California Earthquake Zoning and Probable Maximum Loss Evaluation Program, Los Angeles, CA: California Department of Insurance, 1988, p. 55.

California Division of Mines and Geology. Maps to Accompany Text of San Fernando, California, Earthquake of 9 February 1971. *In* San Fernando, California, Earthquake of 9 February 1971: Bulletin 196, Ed. Gordon B. Oakeshott, Sacramento, CA: California Division of Mines and Geology, 1975.

California Division of Mines and Geology. Alquist-Priolo Workshop Summary: March 15 & 23, 1988, unpublished manuscript, no date, p. 10.

California Employment Development Department. California Unemployment Insurance Reporting Units by Size, Industry and County. Report #524, Employment Development Department, 15 July 1986, p. 62.

California Institute of Technology, and others. The 1983 Coalinga, California Earthquakes. Special Publication 66, Ed. John H. Bennett and Roger W. Sherburne, Sacramento, CA: California Division of Mines and Geology, 1983.

California Office of Statewide Health Planning and Development. Aggregate Profile of Acute Care Hospital Utilization, California 1986. Excluding Federal and State (Non-University) Hospitals. *In* Annual Report of Hospitals (Computer Printout), 31 December 1986.

California Office of Statewide Health Planning and Development. Individual Profile of Acute Care Hospital Utilization; California, Calendar Year 1986. *In* Annual Report of Hospitals (Computer Printout), 20 July 1987.

California Seismic Safety Commission. California at Risk: Steps to Earthquake Safety for Local Government. Report No. SSC 88-01, Sacramento, CA: California Seismic Safety Commission, January 1988, p. 55.

California Seismic Safety Commission. Advance Copy– California at Risk: Reducing Earthquake Hazards 1987-1992. Report No. SSC 88-02, Sacramento, CA: California Seismic Safety Commission, 1 September 1988.

California Seismic Safety Commission. Morgan Hill/Halls Valley: An Initial Assessment, Sacramento, CA: California Seismic Safety Commission, August 1985, p. 53.

California Seismic Safety Commission. Preliminary Reports Submitted to the Seismic Safety Commission on the May 2, 1983 Coalinga Earthquake. *In* Proceedings of the June 9, 1983 Seismic Safety Commission Meeting, Sacramento, CA: California Seismic Safety Commission, 9 June 1983, p. 170.

California Seismic Safety Commission. Preliminary Reports Submitted to the Seismic Safety Commission on the May 2, 1983 Coalinga Earthquake. Transcript of the July 14, 1983 Seismic Safety Commission Meeting in Coalinga, California; Sacramento, CA: California Seismic Safety Commission, 14 July 1983, p. 82.

California Seismic Safety Commission Staff. Selected Damaging California Earthquakes: A Reference to Earthquake Damage with Isoseismal Maps, Ed. K.R. Poeschel and P.A. Stromberg, August 1980, p. 86.

California Seismic Safety Commission, Committee on Hazardous Buildings. Earthquake Safety: Potentially Hazardous Buildings. Report No. SSC 85-04, Sacramento, CA: California Seismic Safety Commission, November 1985, p. 42.

California Seismic Safety Commission, Seismic Safety Element Review Committee. A Review of the Seismic Safety Element Requirement in California. SSC 77-01. A Report to the State of California Seismic Safety Commission, Sacramento, CA: California Seismic Safety Commission, 25 March 1977, p. 29.

California Seismic Safety Commission, Seismic Safety Element Review Committee. A Review of the Seismic Safety Element Requirement in California. SSC 85-05. A Report to the State of California Seismic Safety Commission, Sacramento, CA: California Seismic Safety Commission, 1 August 1985, p. 26.

California Senate Committee on Insurance, Claims and Corporations and Assembly Committee on Finance and Insurance. The Whittier Earthquake: An Examination of Earthquake Insurance Property Damage, Sacramento, CA: Joint Publications, 4 November 1988, p. 78.

California State Geologist. Activities of the California Division of Mines and Geology: July 1, 1985 through June 30, 1986. Report of the State Geologist, Volume 78, Sacramento, CA: California Division of Mines and Geology, 1986, p. 47.

California State Geologist. Activities of the California Division of Mines and Geology: July 1, 1984 through June 30, 1985. Report of the State Geologist, Volume 77, Sacramento, CA: California Division of Mines and Geology, 1985, p. 55.

Camerer, Colin F., and Howard Kunreuther. Decision Processes for Low Probability Events: Policy Implications. *In* Journal of Policy Analysis and Management, Volume 8, No. 4, Fall 1989, p. 565-592.

Campbell, Ian. The Influence of Geologic Hazards on Legislation in California. *In* California Geology, October 1977, p. 219-223.

Castle, Gray, Cushman, Robert F., and Kensicki, Peter R., Eds. The Business Insurance Handbook, Homewood, Illinois: Dow Jones-Irwin, 1981, p. 753.

Christopherson. R.L. Earthquake Hazard Reduction Efforts by the City of San Diego. *In* Future Directions in Evaluating Earthquake Hazards of Southern California. U.S. Geological Survey Open-File Report 86-401, 1986, p. 378-381.

City of Los Angeles Emergency Operations Organization. Whittier Narrows Earthquakes, October 1 and 4, 1987: After Action Report of the City's Emergency Operations Organization, City of Los Angeles, Date unknown, p. 127.

City of Los Angeles Fire Department. Earthquake Emergency Operational Plan, Los Angeles City Fire Department, 1987, p. 36.

Cochrane, Harold C. Natural Hazards and Their Distributive Effects, PB-262 021, Boulder, CO: Institute of Behavioral Science, The University of Colorado, 1975, p. 135.

Corrado, Manni, M.D., and Paderni, Sergio, M.D. The Earthquake in Italy in 1980. *In* Disaster Medicine, Volume 1, Fall 1983, p. 413-414.

Crough, Edmund A.C.; Wilson, Richard. Risk/Benefit Analysis, Cambridge, MA: Ballinger Publishing Company, 1982, p. 218.

Dacy, Douglas C., and Howard Kunreuther. The Economics of Natural Disasters; Implications for Federal Policy, New York, NY: The Free Press, 1969, p. 270.

Davis, J.F., J.H. Bennett, and others. Earthquake Planning Scenario for a Magnitude 8.3 Earthquake on the San Andreas Fault in Southern California. Special Publication 60, Sacramento, CA: California Division of Mines and Geology, 1982, p. 128.

Davis, James F., John H. Bennett, and others. Earthquake Planning Scenario for a Magnitude 8.3 Earthquake on the San Andreas Fault in the San Francisco Bay Area. Special Publication 61, Sacramento, CA: California Division of Mines and Geology, 1982.

De, P.K., D. Acharya, and K.C. Sahu. A Chance-Constrained Goal Programming Model for Capital Budgeting. *In* Journal of the Operational Research Society, Volume 33, No. 7, 1982, p. 635-638.

De Bruycker, Marc, and others. The 1980 Earthquake in Southern Italy: Rescue of Trapped Victims and Mortality. *In* Bulletin of the World Health Organization, Volume 61, No. 6, 1983, p. 1021-1025.

de Ville de Goyet, C., and others. Earthquake in Guatemala: Epidemiologic Evaluation of the Relief Effort. *In* Bulletin of the Pan American Health Organization, Volume X, No. 2, 1976, p. 95-109.

Diggs, David M. Risk Communication, Lessons from Natural Hazards: An Annotated Bibliography. Topical Bibliography #15, Boulder, CO: Natural Hazards Research and Applications Information Center, 1988, p. 112.

Domres, B., M.D., P. Dürner, and R. Heinrich, M.D. The Earthquake in Algeria in 1980. *In* Disaster Medicine, Volume 1, Fall 1983, p. 421-424.

Duke, C. Martin, and Donald F. Moran. Earthquakes and City Lifelines. *In* The San Fernando Earthquake of February 9, 1971 and Public Policy. Ed. George O. Gates. Special Subcommittee of the Joint Committee on Seismic Safety, California Legislature, July 1972, p. 53-71.

Durkin, Michael E. Injuries Resulting from Earthquake Damage, Woodland Hills, CA: Durkin and Associates, Date unknown, p. 11.

Earthquake Engineering Research Institute. U.S.-Mexico Workshop on 1985 Mexico Earthquake Research - Proceedings, El Cerrito, CA: Earthquake Engineering Research Institute, April 1987, p. 148.

Earthquake Engineering Research Institute. Loma Prieta Earthquake Reconnaissance Report. Earthquake Spectra. Supplement to Volume 6, May 1990, p. 448.

Earthquake Research Affiliates Conference. Earthquakes and Insurance. Conference of the Earthquake Research Affiliates, April 2-3, 1973, Pasadena, CA: Center for Research on the Prevention of Natural Disasters, Division of Engineering and Applied Science, California Institute of Technology, July 1973.

Echevarria, J.A., K.A. Norton, and R.D. Norton. Community Response to an Earthquake Forecast: A Case Study in Peru. *In* Methods Development for Benefit-Cost Analysis of Natural Hazards Information, Laramie, WY: The Institute for Policy Research, University of Wyoming, October 1983, p. 7.1 - 7.27.

Elliot, Steve. Earthquake insurance partnership sought, Hawaii Tribune-Herald, 17 May 1989, p. 12.

Ellson, Richard W., Jerome W. Milliman, and R. Blaine Roberts. Measuring the Regional Economic Effects of Earthquakes and Earthquake Predictions. *In* Journal of Regional Science, Volume 24, No. 4, 1984, p. 559-579.

EQE Engineering. EQE Engineering: Portfolio Analyses and the EQE Earthquake Risk Reduction Program, San Francisco, CA: EQE Engineering, no date, p. 19.

Eu, March Fong. Roster: California State, County, City and Township Officials, and State Officials of the U.S., Sacramento, CA: March Fong Eu, Secretary of State, 1988, p. 211.

Executive Office of the President, Office of Science and Technology. Report of the Task Force on Earthquake Hazard Reduction, Washington, D.C.: U.S. Government Printing Office, September 1970, p. 54.

Federal Emergency Management Agency. National Earthquake Hazards Reduction Program: Fiscal Year 1987 Activities. Report to the United States Congress, Washington, D.C.: Federal Emergency Management Agency, no date.

Federal Emergency Management Agency. National Earthquake Hazards Reduction Program. Recommended Provisions for the Development of Seismic Regulations for New Buildings, Part 2 Commentary, Washington, D.C.: Federal Emergency Management Agency, Earthquake Hazards Reduction Series 18, 1985.

Federal Emergency Management Agency; NSC Committee on Assessment of Consequences and Preparations for a Major California Earthquake. An Assessment of the Consequences and Preparations for a Catastrophic California Earthquake: Findings and Actions Taken, Washington, D.C.: Federal Emergency Management Agency, November 1980, p. 59.

Finance, Insurance, and Monetary Services Committee, Inc. Data Processing Facilities: Guidelines for Earthquake Hazard Mitigation, Sacramento, CA: FIMS, Inc., June 1987, p. 1.1 - 10.8.

FitzSimmons, Ann R. Natural Hazards and Land Use Planning: An Annotated Bibliography. Topical Bibliography 11, Boulder, CO: Natural Hazards Research and Applications Center, 1984, p. 103.

Freeman, John Ripley. Earthquake Damage and Earthquake Insurance, New York: McGraw-Hill, 1932, p. 904.

French, Steven P., and Deborah Harmon. Current Land Use Planning for Seismic Safety in California. Unpublished manuscript prepared for Rice Center, Houston, Texas, 7 May 1982, p. 12.

French, Steven P., and Mark S. Isaacson. Applying Earthquake Risk Analysis Techniques to Land Use Planning. *In* APA Journal, Autumn 1984, p. 509-522.

Friedman, Don G. Earthquake Losses Under Workers Compensation and General Liability; Estimates for a "Worst Case" Event in Greater Los Angeles, Oak Brook, IL: All-Industry Research Advisory Council, October 1988, p. 72.

Friedman, Milton, and Savage, L. J. The Utility Analysis of Choices Involving Risk. *In* Journal of Political Economy. Volume LVI, No. 4, August 1948, p. 279-304.

Gates, William E. Mitigation of Earthquake Effects on Hospital Facilities Los Angeles: Dames & Moore, Date unknown, p. 14.

Geologic Hazards Advisory Committees for Program and Organization. Earthquake and Geologic Hazards in California. A Report to the Resources Agency, Sacramento, CA: Geologic Hazards Advisory Committees for Program and Organization, 26 April 1967, p. 18.

Gere, James M., and Haresh C. Shah. Earthquakes: How to Protect Your Life and Property, Stanford, CA: Department of Civil Engineering, Stanford University, 1980, p. 16.

Glass, Roger I., and others. Earthquake Injuries Related to Housing in a Guatemalan Village. *In* Science, Volume 197, 12 August 1977, p. 638-643.

Gold, Bela. The Shaky Foundations of Capital Budgeting. *In* California Management Review, Volume XIX, No. 2, Winter 1976, p. 51-60.

Gordon, Myron J. A Portfolio Theory of the Social Discount Rate and the Public Debt. *In* Journal of Finance, Volume XXXI, No. 2, May 1976, p. 199-214.

Gordon, P., and others. Evaluation of Mitigation Strategies for Disaster Events, Los Angeles: University of Southern California, School of Urban and Regional Planning, 17 February 1986, p. 228.

Governor's Office of Emergency Services. Emergency Plan Sacramento, CA: Governor's Office of Emergency Services, 1982, p. 368.

Governor's Office of Emergency Services. Response '87 Exercise Plan: Southern California Regional Earthquake Response; Planning; Earthquake Exercise, Sacramento, CA: Governor's Office of Emergency Services, September 1987, p. 66.

Governor's Office of Emergency Services. Earthquake Response Plan: Southern San Andreas, Sacramento, CA: Governor's Office of Emergency Services, July 1983, p. 228.

Governor's Office of Emergency Services. Emergency Public Information Excerpt from Multihazard Functional Planning Guidance, Sacramento, CA: Governor's Office of Emergency Services, May 1985.

Governor's Office of Emergency Services. State EBS Operations Plan, Sacramento, CA: Governor's Office of Emergency Services, March 1987, p. 16.

Governor's Office of Emergency Services, Telecommunication Division. Statewide Mutual Aid Radio System Plan (SMARS), Sacramento, CA: Governor's Office of Emergency Services, Telecommunications Division, July 1986, p. 13.

Governor's Office of Emergency Services, Telecommunications Division. California On-Scene Emergency Coordination Radio Plan (CALCORD), Sacramento, CA: Governor's Office of Emergency Services, Telecommunications Division, July 1986, p. 5.

Governor's Office of Emergency Services. Earthquake Response Plan, Sacramento, CA: Governor's Office of Emergency Services, November 1977, p. I-1 to III-4.

Governor's Office of Emergency Services. State Emergency Public Information Organization: Standard Operating Procedures - Level 1 & Level 2, Sacramento, CA: Governor's Office of Emergency Services, 11 August 1987, p. 14.

Governor's Office of Planning and Research. The California Planner's 1988 Book of Lists. Ed. De Ann Baker, Renee Kucewicz, and Katherine Hatch, Sacramento, CA: Governor's Office of Planning and Research, 1988, p. 107.

Governor's Office of Planning and Research. State of California General Plan Guidelines, Sacramento, CA: Governor's Office of Planning and Research, June 1987, p. 368.

Greene, Mark R. Risk and Insurance, Burlingame, CA: Southwestern Publishing Company, 1968, p. 854.

Haas, J. Eugene, and Dennis S. Mileti. Socioeconomic Impact of Earthquake Prediction on Government, Business, and Community. *In* California Geology, Volume 30, No. 7. July 1977, p. 147-157.

Haley, S., R. Christopherson, V. Berger, and D. Streiff. Liquefaction Potential in San Diego. Proceedings 1985 Convention, Structural Engineers Association of California, October 3,4,5, San Diego, CA, p. 24-40.

Hare, Jeffrey B. Earthquake Insurance: A Proposal for Compulsory Coverage. *In* Santa Clara Law Review, Volume 24, No. 4, Fall 1984, p. 971-997.

Harlow, Kirk C., and Duane Windsor. Integration of Cost-Benefit and Financial Analysis in Project Evaluation. *In* Public Administration Review, Volume 48, No. 5, September/October 1988, p. 918-928.

Hart, Earl W. Fault-Rupture Hazard Zones in California. *In* Special Publication 42, Sacramento, CA: California Department of Conservation, Division of Mines and Geology, 1988, p. 24.

Hays, Walter W. Proceedings of Conference V Communicating Earthquake Hazard Reduction Information, Washington, D.C.: U.S. Geological Survey, 1978, p. 425.

Hays, Walter W., Ed. Communicating Earthquake Hazard Reduction Information. *In* Proceedings of Conference V of U.S.G.S., May 22-24, 1978. Open-File Report 78-933, Menlo Park, CA: U.S. Geological Survey, 1978, p. 426.

Hill, Mary R., and others. San Fernando, California Earthquake of 9 February 1971: Bulletin 196, Ed. Gordon B. Oakeshott, Sacramento, CA: California Division of Mines and Geology, 1975, p. 463.

Hingson, Robert A., M.D., and Luke Hingson. Respiratory Injuries in Earthquakes in Latin America in the 1970's - A Personal Experience in Peru, 1970; Nicaragua, 1972-73; and Guatemala, 1976. *In* Disaster Medicine, Volume 1, Fall 1983, p. 425-426.

Holden, Richard, Richard Lee, and Michael Reichle. Technical and Economic Feasibility of an Earthquake Warning System in California. Special Publication 101, Sacramento, CA: California Department of Conservation, Division of Mines and Geology, March 1989, p. 97.

Horsak, Randy D., and Sam A. Damico. Selection and Evaluation of Hazardous Waste Disposal Sites Using Fuzzy Set Analysis. *In* Proceedings of the 78th Annual Meeting of the Air Pollution Control Association, Detroit, Michigan, June 16-21, 1985, p. 1-17.

Huff, J. L. Policy Implications of Legal Liability for Government Involvement in Earthquake Engineering. *In* Proceedings of the Eighth World Conference on Earthquake Engineering, July 21-28, 1984, San Francisco, California, U.S.A., Volume VII, Englewood Cliffs, NJ: Prentice-Hall, 1984.

Huffman, James. Government Liability and Disaster Mitigation: A Comparative Study, Lanham, MD: University Press of America, 1986.

Huffman, M.E., and C.F. Armstrong. Geology for Planning in Sonoma County. Special Report 120, Sacramento, CA: California Division of Mines and Geology, 1980, p. 31.

Inglesias, J. Intensity Map for the Earthquake of September 19, 1985. *In* Lessons Learned from the 1985 Mexico Earthquake. Earthquake Engineering Research Institute, 1989, p. 9-14.

Insurance Services Office. Guide for Determination of Earthquake Classifications. 1983 Edition, San Francisco, CA: Insurance Services Office, 1983, p. 24.

International Conference of Building Officials. Uniform Building Code, 1988 Edition. International Conference of Building Officials, Whittier, CA: International Conference of Building Officials, 1988.

Jaffe, Martin, JoAnn Butler, and Charles Thurow. Reducing Earthquake Risks: A Planner's Guide, Chicago, IL: American Planning Association, October 1981, p. 82.

Joint Committee on Seismic Safety of the California Legislature. Earthquake Risk. October 31, 1971 Interim Report of the Special Subcommittee on the San Fernando Earthquake Study, Conference Proceedings September 22-24, 1971, Sacramento, CA: Joint Committee on Seismic Safety of the California Legislature, 31 October 1971.

Joint Committee on Seismic Safety, California Legislature. A Comprehensive Approach to Seismic Safety. Meeting the Earthquake Challenge, Volume 1, San Jose, CA: Joint Committee on Seismic Safety, January 1974, p. 32.

Joint Panel on the San Fernando Earthquake, National Academy of Sciences, National Academy of Engineering. The San Fernando Earthquake of February 9, 1971: Lessons from a Moderate Earthquake on the Fringe of a Densely Populated Region, Washington, D.C.: National Academy of Sciences, 1971, p. 24.

Jones, L.M., and others. The North Palm Springs, California, Earthquake Sequence of July 1986, Pasadena, CA: California Institute of Technology, Date unknown, p. 16.

Jury Verdicts Weekly, Inc. Jury Verdicts from Cases in California, 1986-1988, Involving Loss of Life, Eyesight or Limbs to Gainfully Employed Persons Between the Ages of 18 and 65. Photocopied case materials, 1988.

King, Elizabeth M., and James P. Smith. Computing Economic Loss in Cases of Wrongful Death. R-3549-ICJ, Santa Monica, CA: The Institute for Civil Justice, Rand Corporation, 1988, p. 130.

Kirby, Robert. Priority Indexing: An Approach to Capital Budgeting in the Government Sector. *In* Government Accountant's Journal, Volume 25, No. 3, Fall 1976, p. 56-60.

Kitzmiller, Carla. Proceedings of Conference XL: A Workshop on "The U.S. Geological Survey's Role in Hazards Warnings." Ed. Walter W. Hays and Paula L. Gori, Denver, CO: U.S. Geological Survey, 1987, p. 119.

Kockelman, W. J. Use of U.S. Geological Survey Earth-Science Products by Selected Regional Agencies in the San Francisco Bay Region, California. *In* Open-File Report No. 79-221, Menlo Park, CA: U.S. Geological Survey, 1979, p. 173.

Kockelman, W. J., and J. I. Ziony. The Earthquake Threat. *In* Evaluating Earthquake Hazards in the Los Angeles Region. U.S. Geological Survey Professional Paper 1360, Ed. J. I. Ziony, Washington D.C: U.S. Geological Survey, 1985, p. 1-14.

Kockelman, W.J. Using Earth-Science Information for Earthquake Hazard Reduction. *In* Evaluating Earthquake Hazards in the Los Angeles Region. U.S. Geological Survey Professional Paper 1360, Ed. J .I. Ziony, Washington, D.C.: U.S. Government Printing Office, 1985, p. 443-505.

Kockelman, William J. Examples of the Use of Geologic and Seismologic Information for Earthquake-Hazard Reduction in Southern California. Prepared for the 8th World Conference on Earthquake Engineering, San Francisco, CA; Menlo Park, CA: U.S. Geological Survey, July 1984.

Kockelman, William J. Reducing Losses from Earthquakes through Personal Preparedness. *In* Open-File Report 84-765, Washington, D.C.: U.S. Geological Survey, 1984, p. 13.

Kockelman, William J. Some Techniques for Reducing Landslide Hazards. *In* Bulletin of the Association of Engineering Geologists, Volume 23, No. 1, 1986, p. 29-52.

Kockelman, William J., and Robert D. Brown, Jr. Geology for Decisionmakers: Protecting Life, Property, and Resources. *In* Public Affairs Report, Volume 26, No. 1, Menlo Park, CA: U. S. Geological Survey, February 1985, p. 11.

Kunreuther, Howard. Recovery from Natural Disasters Washington, D.C.: American Enterprise Institute for Public Policy Research, December 1973, p. 71.

Kunreuther, Howard, and others. Limited Knowledge and Insurance Protection: Implications for Natural Hazard Policy. Prepared for the National Science Foundation, Philadelphia, PA: Wharton School, March 1977, p. 1.1 - 13.106.

Kunreuther, Howard, and others. Disaster Insurance Protection, Public Policy Lessons, New York, NY: John Wiley & Sons, 1978, p. 391.

Kunreuther, Howard, and others. An Interactive Modeling System for Disaster Policy Analysis, Boulder, CO: Institute of Behavioral Science, 1978, p. 137.

Lambrig, W.H. Role of States in Earthquake and Natural Hazard Innovation at the Local Level: A Decision-Making Study, New York, NY: Syracuse Research Corp., December 1984, p. 338.

Leighton, F. B. Urban Landslides: Targets for Land-Use Planning in California, Geological Society of America, Special Paper 174, 1976, p. 37-60.

Low, Charlotte. Coalinga Quake Causes Tremors in Insurance Law. *In* The Daily Journal, 1 August 1983, p. 1.

Marston, Sallie A. A Political Economy Approach to Hazards: A Case Study of California Lenders and the Earthquake Threat. Natural Hazard Research Working Paper 49, Boulder, CO: University of Colorado, February 1984, p. 27.

Mathewson, Stuart B., E.W. Blanch Co. Creating Realistic Earthquake Probable Maximum Loss Estimates. Paper presented at CPCU Earthquake Conference, Honolulu, Hawaii, May 16, 1989, p. 13.

Matsushima, Minoru. Earthquake Insurance in Japan. Paper presented to CPCU Conference on Earthquakes and Insurance, Honolulu, Hawaii, 16 May 1989, p. 14.

May, Peter J., and Patricia A. Bolton. Reassessing Earthquake Hazard Reduction Measures. *In* Journal of the American Planning Association, Volume 52, No. 4, 1986, p. 443-451.

McCann, John P. Using Shaking-Hazard Evaluations for Private Investment Consideration. *In* Proceedings of Conference XXXII of U.S.G.S., Los Angeles, CA, 1985; A Workshop on Evaluating the Shaking Hazard for Redevelopment Decisions. Open-File Report 86-401. Ed. W. M. Brown III, W. J. Kockelman, J.I. Ziony, and C.C. Ramweyer, Menlo Park, CA: U.S. Geological Survey, date unknown, p. 371-375.

McLean, John G. How to Evaluate Capital Investments. *In* Harvard Business Review, Volume 36, No. 6, November-December 1958, p. 59-69.

Mileti, Dennis S., Janice R. Hutton, and John H. Sorenson. Earthquake Prediction Response and Options for Public Policy, Boulder, CO: Institute of Behavioral Science, University of Colorado, 1981, p. 152.

Mintier, Laurence J., and Peter Arne Stromberg. Seismic Safety at the Local Level: Does Planning Make a Difference? *In* Special Publication 62. Ed. Earl W. Hirschfeld, Sacramento, CA: California Division of Mines and Geology, 1982, p. 425-437.

Mishan, E.J. Economics for Social Decisions: Elements of Cost-Benefit Analysis, New York, NY: Praeger Publishers, 1973, p. 151.

Mishan, E.J. Cost-Benefit Analysis, New York, NY: Praeger Publishers, 1976, p. 454.

Mittler, Elliott. Natural Hazard Policy Setting: Identifying Supporters and Opponents of Nonstructural Hazard Mitigation, Boulder, CO: Institute of Behavioral Science, University of Colorado, 1989, p. 267.

Monroe, Vincent, Ph.D. California's Earthquake Threat: Are Lawmakers Interested? Sacramento, CA: California Seismic Safety Commission, May 1983, p. 13.

Mukerjee, Tapan. Adjusting to Earthquakes: Costs and Benefits. Earthquake Risk: Interim Report of the Special Subcommittee on the San Fernando Earthquake Study, 31 October 1971, p. 55-59.

Munich Reinsurance Company. Earthquake Mexico '85, Munich, FRG: Munich Reinsurance Company, 1986, p. 71.

Mushkatel, Alvin H., and Joanne M. Nigg. The Effect of Objective Risk on Key Factor Support for Seismic Mitigation Policy. *In* Working Paper 102. Ed. James P. Cooper, Tempe, AZ: Office of Hazards Studies, School of Public Affairs, Arizona State University, November 1986, p. 21.

Mushkatel, Alvin H., and Joanne M. Nigg. Opinion Congruence and the Formulation of Seismic Safety Policies. *In* Working Paper 104. Ed. James P. Cooper, Tempe, AZ: Office of Hazards Studies, School of Public Affairs, Arizona State University, November 1986, p. 16.

National Research Council. Committee on Earthquake Engineering. Liquefaction of Soils During Earthquakes, Washington, D.C.: National Academy Press, 1985.

National Research Council. Committee on Socioeconomic Effects of Earthquake Predictions. A Program of Studies on the Socioeconomic Effects of Earthquake Predictions, Washington, D.C.: National Academy Press, 1978, p. 162.

National Research Council. Panel on Earthquake Loss Estimation Methodology. Estimating Losses from Future Earthquakes, Washington, D.C.: National Academy Press, 1989, p. 231.

National Research Council. Panel on Seismic Hazard Analysis. Probabilistic Seismic Hazard Analysis, Washington, D.C.: National Academy Press, 1988, p. 97.

Nichols, D.R., and J.M. Buchanan-Banks. Seismic Hazards and Land-Use Planning, Washington D.C.: U.S. Geological Survey, 1974, p. 33.

Nigg, Joanne. Awareness and Behavior: Public Response to Prediction Awareness. *In* Perspectives on Increasing Hazard Awareness. Ed. Thomas F. Saarinen, Boulder, CO: Institute of Behavioral Science, 1982, p. 71-96.

Nigg, Joanne M. The Issuance of Earthquake "Predictions": Information Diffusion and Public Response. *In* Working Paper 101. Ed. James P. Cooper, Tempe, AZ: Office of Hazards Studies, School of Public Affairs, Arizona State University, November 1986, p. 20.

Nigg, Joanne M. Communication and Behavior: Organization and Individual Response to Warnings. *In* Working Paper 106. Ed. James P. Cooper, Tempe, AZ: Office of Hazards Studies, School of Public Affairs, Arizona State University, November 1986, p. 20.

Nigg, Joanne M., and Alvin H. Mushkatel. Utilization of Services Following a Federally-Declared Disaster. *In* Working Paper 105. Ed. James P. Cooper, Tempe, AZ: Office of Hazards Studies, School of Public Affairs, Arizona State University, November 1986, p. 19.

Olson, Robert A. Individual and Organizational Dimensions of the San Fernando Earthquake. *In* San Fernando, California, Earthquake of February 9, 1971. Ed. N.A. Benfer, J.L. Coffman, J.R. Bernick, and L.T. Dees, Volume 2, Washington, D.C.: U.S. Government Printing Office,1973, p. 257-292.

Palm, Risa. Does a Mandated Insurance Offer Affect the Propensity to Purchase Earthquake Insurance? Paper presented to the Society of Risk Analysis, San Francisco, 1989, p. 32.

Palm, Risa. Real Estate Agents and Special Studies Zones Disclosure: The Response of California Home Buyers to Earthquake Hazards Information, Boulder, CO: Institute of Behavioral Science, 1981, p. 147.

Palm, Risa I. Experiences and Opinions of Lenders Which Do Take Earthquake Hazards into Account in their Mortgage Lending Policies, Unpublished manuscript, 4 June 1984, p. 9.

Palm, Risa I., and others. Home Mortgage Lenders, Real Property Appraisers and Earthquake Hazards, Boulder, CO: Institute of Behavioral Science, 1983, p. 152.

Pate, Marie-Elisabeth, and Haresh C. Shah. Public Policy Issues: Earthquake Prediction. *In* Bulletin of the Seismological Society of America, Volume 69, No. 5, October 1979, p. 1533-1547.

Perry, Don. California Regions: San Diego. Information Brochure, Sacramento, CA: California Department of Commerce, March 1987.

Perry, Don. California Regions: Inland Empire. Information Brochure, Sacramento, CA: California Department of Commerce, March 1987.

Perry, Don. California Regions: Los Angeles. Information Brochure, Sacramento, CA: California Department of Commerce, March 1987.

Perry, Don. California Regions: Central Coast. Information Brochure, Sacramento, CA: California Department of Commerce, March 1987.

Perry, Don. California Regions: San Joaquin Valley. Information Brochure, Sacramento, CA: California Department of Commerce, March 1987.

Petak, William J. and Arthur A. Atkisson. Natural Hazard Risk Assessment and Public Policy, New York, NY: Springer-Verlag, 1982.

Powers, James E., Terence P. Haney, and Neil A. Allgood. Southern California Earthquake Response Plan, Center for Planning and Research, Inc., December 1986, p. 200+.

Rand Corporation, Institute for Civil Justice. Executive Summaries of the Aviation Accident Study, R-3684-ICJ, Santa Monica, CA: Rand Corporation, 1988.

Real, C.R., T.R. Toppozada, and D.L. Parke. Earthquake Epicenter Map of California, Map Sheet 39, Sacramento, CA: California Division of Mines and Geology, 1978.

Regulska, Joanna. Public Awareness Programs For Natural Hazards. *In* Perspectives on Increasing Hazard Awareness, p. 36-70.

Reitherman, Robert. Reducing the Risks of Nonstructural Earthquake Damage: A Practical Guide. Earthquake Hazards Reduction Series 1, Redwood City, CA: Scientific Service Inc., June 1985, p. 87.

Reitherman, Robert. Reducing the Risks of Nonstructural Earthquake Damage: A Practical Guide. Prepared for the Southern California Earthquake Preparedness Project Sacramento, CA: California Seismic Safety Commission, February 1983, p. 87.

Reitherman, Robert M. A Review of Earthquake Damage Estimation Methods. *In* Earthquake Spectra, Volume 1, No. 4, Berkeley, CA: Earthquake Engineering Research Institute, August 1985, p. 805-847.

Reitherman, Robert M., and David J. Leeds. A Study of the Effectiveness of the Alquist-Priolo Program. Prepared for the Division of Mines and Geology, Sacramento, CA, August 1990, p. 131.

Richter, Charles F. Elementary Seismology: San Francisco, CA, W. H. Freeman and Company, 1958.

Riemer, Wesley N. Worldwide Catastrophe Reserve Tax Issues. Paper Presented to CPCU Conference on Earthquakes and Insurance, Honolulu, Hawaii; Philadelphia, PA: Price Waterhouse, 17 May 1989, p. 8.

Roberts, R. Blaine, and others. Earthquakes and Earthquake Predictions: Simulating Their Economic Effects, Columbia, SC: South Carolina University, 30 September 1982, p. 270.

Roquemore, Glenn R., and Thomas Heaton. The Earthquake Threat to Naval Operational Readiness: A Proposal for Protection of the San Diego Naval Facilities. Proposal to the U.S. Department of the Navy September 1987, p. 23.

Saarinen, Thomas F. The Relation of Hazard Awareness to Adoption of Mitigation Measures. *In* Perspectives on Increasing Hazard Awareness. Ed. Thomas F. Saarinen, Boulder, CO: Institute of Behavioral Science, 1982, p. 1-35.

Salkin, E. Lawrence, and Debra A. Lindsey. Use of Microcomputers to Assess the Economic Impacts of the Earthquake/85 Exercise. Unpublished paper presented to Society for Computer Simulation Multiconference, San Diego, CA, 23-25 January 1986, p. 49-53.

Scawthorn, Charles. Comprehending Earthquake Conflagration, San Francisco, CA: EQE Engineering, May 1989.

Scawthorn, Charles. Seismic Risk: State-of-the-Art. *In* Proceedings of Review Meeting of U.S.-Japan Cooperative Research on Seismic Risk Analysis and Its Application to Reliability-Based Design of Lifeline Systems. National Science Foundation and Japan Society for the Promotion of Science, January 1981, p. 89-109.

Scawthorn, Charles. Fire Following Earthquake: Estimates of the Conflagration to Insured Property in Greater Los Angeles and San Francisco, Oak Brook, IL: All-Industry Research Advisory Council, 1987, p. 83.

Scholl, Roger E., and Onder Kustu. Procedures and Data Bases for Earthquake Damage Prediction and Risk Assessment. *In* Proceedings of Conference XIII, U.S.G.S., August 25-27, 1980: Evaluation of Regional Seismic Hazards and Risk, Open-File Report 81-437. Ed. Walter W. Hays, Menlo Park, CA: U.S. Geological Survey, 1981, p. 164-208.

Scott, Stanley. Research Applications: Perspectives on the California Seismic Safety Commission. Working Paper 88-3 Berkeley, CA: Institute of Governmental Studies, UCB, 1987, p. 9.

Scott, Stanley. Earthquake Engineering and Public Policy: Key Strategies for Seismic Policy. Working Paper 88-2, Berkeley, CA: Institute of Governmental Studies, UCB, 1986, p. 11.

Seed, H. B., J. Lysmer, M. P. Romo, and A. Jaime. Ground Response Effects in the Mexico City Earthquake of September 19, 1985. *In* Lessons Learned from the 1985 Mexico City Earthquake: Earthquake Engineering Research Institute, Report 89-02, p. 74-77.

Seelig, Anita. EDS Develops Computer Flood Program to Protect Lenders. *In* Mortgage Banking, November 1988, p. 82-86.

Shimoyama, Hiroya, The Tokio Marine & Fire Insurance Co., Ltd. Earthquake Insurance on Dwelling Risks in Japan. Paper presented at CPCU Earthquake Conference, Honolulu, Hawaii, May 16, 1989, p. 5.

Sidel, R.C., A.J. Pearce, and C.L. O'Laughlin. Hillslope Stability and Land Use. American Geophysical Union Water Resources Monograph No. 11, 1985.

Smolka, A., and G. Berz. The Mexico Earthquake of September 19, 1985 – An Analysis of the Insured Loss and Implications for Risk Assessment. *In* Earthquake Spectra, Volume 5, No. 1, 1989, p. 223-247.

Solomons, Noel W., M.D., and Nancy Butte, B.S. A View of the Medical and Nutritional Consequences of the Earthquake in Guatemala. *In* Public Health Reports, Volume 93, No. 2, March-April 1978, p. 161-169.

Sood, Rahul. Communicating for Improved Hazard Awareness. *In* Perspectives on Increasing Hazard Awareness. Ed. Thomas F. Saarinen, Boulder, CO: Institute of Behavioral Science, 1982, p. 97-129.

Spangle, William E., Ed. Pre-Earthquake Planning for Post-Earthquake Rebuilding, Portola Valley, CA: William Spangle and Associates, 1987, p. 77-90.

Steinbrugge, K.V., and others. Metropolitan San Francisco and Los Angeles Earthquake Loss Studies: 1980 Assessment. *In* U.S. Geological Survey Open-File Report 81-113, Washington, D.C.: U.S. Department of the Interior, 1981, p. 13.

Steinbrugge, K.V., S.T. Algermissen, and H.J. Lagorio. Determining Monetary Losses and Casualties for Use in Earthquake Mitigation and Disaster Response Planning. *In* Eighth World Conference on Earthquake Engineering, Volume VII, El Cerrito, CA: Earthquake Engineering Research Institute, 1984, p. 615-622.

Steinbrugge, Karl V., and others. Earthquake Hazard Reduction: Program Priorities, Washington, D.C.: Office of Science and Technology, Executive Office of the President, September 1970, p. 54.

Steinbrugge, Karl V., and others. Earthquake Planning Scenario for a Magnitude 7.5 Earthquake on the Hayward Fault in the San Francisco Bay Area. Special Publication 78, Sacramento, CA: California Department of Conservation, Division of Mines and Geology, 1987, p. 243.

Stewart, Jill. Quake a Mile from City Hall Jiggles L.A. *In* Los Angeles Times, 10 June 1988, p. 3.

Sunset Magazine. Getting Ready for the Big Quake. *In* Sunset Special Report, Menlo Park, CA: Sunset Magazine, March 1982, p. 104-111.

The Center for Research on the Prevention of Natural Disasters. Earthquakes and Insurance, Pasadena, CA: California Institute of Technology, 1973, p. 152.

The Earthquake Project, National Committee on Property Insurance. Catastrophic Earthquakes: The Need to Insure Against Economic Disaster, Boston, MA: National Committee on Property Insurance, March 1989, p. 120.

The Marine and Fire Insurance Associates of Japan. A Pictorial History of Disasters in Japan. English version of "SAIGAI-EZUSHU." The Marine and Fire Insurance Associates of Japan, no date, p. 23.

Thompson, B. The Dazzling Benefits (and Hidden Costs) of Computerized Mapping. Governing, December, 1989, p. 40-46.

Tierney, Kathleen J. Report on the Coalinga Earthquake of May 2, 1983, Sacramento, CA: California Seismic Safety Commission, September 1985, p. 90.

Toppozada, Tousson R. Morgan Hill Earthquake of April 1984. *In* California Geology, Sacramento, CA: California Division of Mines and Geology, July 1984, p. 146-148.

Torres, Kathleen, and Penny Waterstone. Information Sources for Natural Hazards Research–Organizations, Periodicals, Newsletters, and Reference Sources, Boulder, CO: Natural Hazards Research and Applications Information Center, 1977, p. 19.

Townsend, H.K., and M.C. Finan. Economic Impact of the Whittier Narrows Earthquake of October 1, 1987, on the Business Community in the City of Whittier, California. Paper prepared under contract to the California Seismic Safety Commission, 30 January 1988, p. 26.

Tozer, E. Christine. Disaster! Are property insurers prepared? *In* The Brief. Volume 9, No. 3, May 1980, p. 8.

U. S. Geological Survey and California Department of Insurance. Workshop on Earthquake Risk: Information Needs of the Insurance Industry. *In* Proceedings of Workshop in Albuquerque, NM, September 13-15, 1988. U. S. Geological Survey and California Department of Insurance, 1988.

U. S. Geological Survey. Probalistic Estimates of Maximum Acceleration and Velocity in Rock in the Contiguous United States, Menlo Park, CA: U.S. Geoligical Survey Open-File Report 82-1033, 1982.

U. S. Geological Survey. Evaluating Liquefaction Potential. *In* Evaluating Earthquake Hazards in the Los Angeles Region–An Earth-Science Perspective, Menlo Park, CA: U.S. Geological Survey Professional Paper 1360, 1985a, p. 263-315.

U. S. Geological Survey. Predicting Areal Limits of Earthquake-Induced Landsliding. *In* Evaluating Earthquake Hazards in the Los Angeles Region–An Earth-Science Perspective, Menlo Park, CA: U.S. Geological Survey Professional Paper 1360, 1985b, p. 316-345.

U. S. Geological Survey. Probabilities of Large Earthquakes Occurring in California on the San Andreas Fault, Menlo Park, CA: U.S. Geological Survey Open-File Report 88-398, 1988.

U. S. Geological Survey. A Workshop on "USGS's New Generation of Probabilistic Ground Motion Maps and Their Applications to Building Codes," Menlo Park, CA: USGS Open-File Report 89-364, 1989.

U. S. Senate, Committee on Commerce, Science and Transportation. Earthquake Insurance: Problems and Options. S. Print 99-220, Washington, D.C.: U.S. Government Printing Office, 1987, p. 61.

Underwriter's Report. Quake Insured Losses Expected to Hit $1 Billion, San Francisco, CA: Underwriter's Report, Inc., 14 December 1989, p. 12.

Underwriter's Report. Statistical Review Number: A Tabulation of Insurance Company Experience in California During 1988, San Francisco, CA: Underwriter's Report, Inc., 25 May 1989.

Underwriter's Report. Statistical Review Number: A Tabulation of Insurance Company Experience in California During 1987, San Francisco, CA: Underwriter's Report, Inc., 26 May 1988.

Underwriter's Report. Statistical Review Number: A Tabulation of Insurance Company Experience in California During 1986, San Francisco, CA: Underwriter's Report, Inc., 28 May 1987.

Underwriter's Report. Statistical Review Number: A Tabulation of Insurance Company Experience in California During 1985, San Francisco, CA: Underwriter's Report, Inc., 22 May 1986.

Underwriter's Report. Statistical Review Number: A Tabulation of Insurance Company Experience in California During 1984, San Francisco, CA: Underwriter's Report, Inc., 23 May 1985.

Underwriter's Report. Statistical Review Number: A Tabulation of Insurance Company Experience in California During 1983, San Francisco, CA: Underwriter's Report, Inc., 24 May 1984.

Unknown. Earthquake-Nature's Greatest Terror. *In* Insurance Asia, Volume XVIII, No. 4, JAN-FEB 1989, p. 30.

Unknown. Appeal Board Confirms Diablo Canyon Nuclear Plant Earthquake Safety. *In* Public Utilities Fortnightly, Volume 108, No. 2, 16 July 1981, p. 51,52.

Unknown. Computerized Information Retrieval Services Containing Natural Hazards Literature, unpublished manuscript of the Natural Hazards Research and Applications Center, Boulder, CO, no date, p. 7.

Unknown. Earthquake and Flood Insurance. *In* California Geology, August 1973, p. 199.

Vaughn, Christopher K. Notes on Insurance against Loss from Natural Hazards. Natural Hazard Research Working Paper No. 21, Boulder, CO: University of Colorado, 1971, p. 56.

Veek, Eugene B. Earthquake Prediction: The Scientist's Responsibilities and Public Response. *In* California Geology, Volume 34, No. 7, July 1981, p. 134-155.

VSP Associates, Inc. Financial Strategies for California Earthquake Programs. A Report for the Legislature, Sacramento, CA: VSP Associates, Inc., 28 February 1985, p. 1-1 to 4-5.

Weiner, Alan R. The Insurance Industry: An Information Sourcebook, New York, NY: Oryx Press, 1988, p. 266.

Wesnousky, Steven G. Earthquakes, Quaternary Faults, and Seismic Hazard in California. *In* Journal of Geophysical Research, Volume 91, No. B12, 10 November 1986, p. 12,587-12,631.

Wiggins, John H., and Donald F. Moran. Earthquake Safety in the City of Long Beach Based on the Concept of "Balanced Risk," Long Beach, CA: J. H. Wiggins Company, 28 May 1970, p. 43.

Wiggins, John H., and others. Seismic Safety Study, City of Los Angeles. Technical Report 74-1199-1 for the Planning Department, City of Los Angeles; Redondo Beach, CA: J. H. Wiggins Company, 30 April 1974, p. I.1 - X.6.

Wiggins, John H., Donald F. Moran, and C. Wayne Parish. Earthquake Damage Inspection Manual: The San Fernando Earthquake of February 9, 1971, Palos Verdes Estates, CA: J. H. Wiggins Company, April 1972, p. 87.

Wiggins, John H., James E. Slosson, and James P. Krohn. Natural Hazards: Earthquake, Landslide, Expansive Soils - Loss Models, Redondo Beach, CA: J.H. Wiggins Company, December 1978, p. 162.

William Spangle and Associates. Geology and Planning: The Portola Valley Experience, Portola Valley, CA: William Spangle and Associates, Inc., 1988a.

William Spangle and Associates. Land Use Planning after Earthquakes, Portola Valley, CA: William Spangle and Associates, 1980, p. 11-23.

William Spangle and Associates. Putting Seismic Safety Policies to Work, Oakland, CA: Bay Area Regional Earthquake Preparedness Project, October 1988b, p. 40.

William Spangle and Associates, and others. Earth Science Information in Land-Use Planning–Guidelines for Earth Scientists and Planners. Geological Survey Circular 721 Alexandria, VA: U.S. Geological Survey, 1976, p. 28.

Wold, R.L. and C.L. Jochim. Landslide Loss Reduction: A Guide for State and Local Government Planning, Denver, CO: Colorado Geological Survey, Department of Natural Resources, 1989.

Woodward-Clyde Consultants. City of Long Beach General Plan, Seismic Safety Element, Long Beach, CA: Department of Planning and Building, October 1988, p. 92.

Woodward-Clyde Consultants. Evaluation of Liquefaction Opportunity and Liquefaction Potential in the San Diego, California Urban Area. Woodward-Clyde Consultants, 1986.

Woodward-Clyde Consultants. Evaluation of Liquefaction Susceptibility in the San Diego, California Urban Area. Woodward-Clyde Consultants, 1982.

Working Group on California Earthquake Probabilities. Probabilities of Large Earthquakes Occurring in California on the San Andreas Fault, Washington D.C: U.S. Geological Survey, 1988, p. 62.

Working, Steering, and Advisory Groups on Earthquake Hazards Reduction. Earthquake Hazards Reduction: Issues for an Implementation Plan, Washington, D.C.: Executive Office of the President, Office of Science and Technology Policy, 1978, p. 231.

Wyner, Alan J. Earthquakes and Risk Level Decisionmaking by California Local Governments. Research Reports, University of California, Davis, Publication Number 42, Davis, CA: Institute of Governmental Affairs, University of California at Davis, 1982, p. 18.

Wyner, Alan J., and Dean E. Mann. Preparing for California's Earthquakes: Local Government and Seismic Safety, Berkeley, CA: Institute of Governmental Studies, University of California at Berkeley, 1986, p. 109.

Wyner, Alan J.,and Dean E. Mann. Seismic Safety Policy in California: Local Governments and Earthquakes, Santa Barbara, CA: University of California, Santa Barbara, Department of Political Science, February 1983, p. 381.

Yager, Ronald R., Ed. Fuzzy Set and Possibility Theory, New York, NY: Pergamon Press, 1982, p. 633.

Yezer, Anthony M., and Claire B. Rubin. The Local Economic Effects of Natural Disasters. Natural Hazard Research Working Paper 61, Boulder, CO: University of Colorado, December 1987, p. 75.

Yung, Shieh, M.D. Experiences of Critical Medical Care after the Earthquake in China in 1976. *In* Disaster Medicine, Volume 1, Fall 1983, p. 427-428.

Ziony, J. I., Ed., Evaluating Earthquake Hazards in the Los Angeles Region: U.S. Geological Survey Professional Paper 1360, 1985, p. 10.

LIST OF APPENDICES

APPENDIX A

CHAPTER 1112, STATUTES OF 1987
AUTHORIZING LEGISLATION FOR URBAN SEISMIC/GEOLOGIC HAZARD MAPPING PROGRAM DESIGN STUDY

Assembly Bill No. 1885

CHAPTER 1112

An act relating to earthquake insurance, making an appropriation therefor, and declaring the urgency thereof, to take effect immediately.

[Approved by Governor September 24, 1987. Filed with Secretary of State September 25, 1987.]

LEGISLATIVE COUNSEL'S DIGEST

AB 1885, Floyd. Earthquake insurance.

Existing law does not require the Department of Insurance to conduct a study of earthquake insurance.

This bill would do so. Among other things, the bill would do all of the following:

(1) Require the department to conduct a study of earthquake insurance and report on the study to the Legislature, as specified.

(2) Define the purpose and scope of the study.

(3) Require the department, in conducting the study, to consult with specified entities.

(4) Require the Department of Conservation to provide certain information and design a specified study.

(5) Appropriate up to $150,000 to the Department of Insurance and appropriate $150,000 to the Department of Conservation from the Insurance Fund for purposes of the bill.

The bill would declare that it is to take effect immediately as an urgency statute.

Appropriation: yes.

The people of the State of California do enact as follows:

SECTION 1. The Department of Insurance shall conduct a comprehensive study of issues related to the provision of earthquake insurance in the State of California and shall prepare a report to be submitted to the Legislature. A preliminary report to be submitted to the Legislature. A preliminary report shall be submitted on or before December 31, 1988, and a final report on or before December 31, 1990.

The purpose and scope of the study shall include, but not be limited to, all of the following:

(a) A recommendation as to courses of action, including legislation or regulation appropriate at the state, federal, or international governmental levels, which should be undertaken to protect California policyholders and California admitted insurers in the event of an earthquake.

(b) A recommendation of state policy as to the continued marketing of earthquake coverage in this state after earthquake predictions by a reputable individual, state, or federal agency, scientific organization, or otherwise, and where the prediction is accorded extensive media coverage.

(c) A recommendation of state policy concerning the marketing of earthquake insurance coverage in this state and availability of that coverage in areas of high earthquake risk.

(d) An analysis of the capacity of insurers to write earthquake coverage on dwellings and contents in this state. The analysis shall also consider the capacity of the reinsurance industry to write and cover dwelling and contents loss from the peril of earthquakes in this state.

(e) A determination based in part on geologic hazards information provided by the Division of Mines and Geology of the Department of Conservation as to the dollar exposure in dwelling insurance written or that could be written on a geographical basis, including a determination as to what areas may have a significant overexposure.

(f) An urban geological hazards mapping study, which shall be designed by the Division of Mines and Geology of the Department of Conservation, using what is learned from that department's effort under subdivision (e), to improve the information available to property owners, local governments, and to the insurance industry regarding geologic-seismic hazards and on the severity and likelihood of ground shaking and related secondary hazards such as liquefaction and slope failure.

In preparing and conducting the report and study of earthquake insurance, the Department of Insurance shall consult with the respective Chairpersons of the Assembly Finance and Insurance Committee and the Senate Insurance, Claims, and Corporations Committee prior to commencing the study and thereafter at least quarterly until the final report is submitted to the Legislature. The department shall also consult with persons who have held the office of Insurance Commissioner since 1970, the Governor's Task Force on Earthquake Hazard Reduction, the State Seismic Safety Commission, The Office of Emergency Services, the current and past consultants to the department on probable maximum loss studies, and other groups, individuals, and agencies as needed. The department is also authorized to retain outside assistance in conducting the study.

SEC. 2 (a) The sum of up to one hundred fifty thousand dollars ($150,000) is hereby appropriated from the Insurance Fund to the Department of Insurance for the purposes of this act, for use during the 1987-88 fiscal year, the 1988-89 fiscal year, the 1989-90 fiscal year, and through December 31, 1990.

(b) The sum of one hundred fifty thousand dollars ($150,000) is hereby appropriated from the Insurance Fund to the Department of Conservation for the purposes of the act, to be allocated in amounts of one hundred thousand dollars ($100,000) for the 1988-89 fiscal year and fifty thousand dollars ($50,000) for the 1989-90 fiscal year.

SEC. 3 This act is an urgency statute necessary for the immediate preservation of the public peace, health, or safety within the meaning of article IV of the Constitution and shall go into immediate effect. The facts constituting the necessity are:

In order to provide available and adequate insurance coverage for protection from the peril of earthquakes for all Californians, it is essential that the Legislature and the Governor have and indication on the potential economic loss to the insurance industry in the event of a major earthquake in California. Therefore, it is necessary that this act take effect immediately.

APPENDIX B

MODIFIED MERCALLI INTENSITY SCALE OF WOOD AND NEUMAN

MODIFIED MERCALLI INTENSITY SCALE OF 1931

The first scale to reflect earthquake intensities was developed by de Rossi of Italy, and Forel of Switzerland, in the 1880s. This scale, with values from I to X was used for about two decades. A need for a more refined scale increased with the advancement of the science of seismology, and in 1902 the Italian seismologist, Mercalli, devised a new scale on a I to XII range. The Mercalli Scale was modified in 1931 by American seismologists Harry O. Wood and Frank Neumann to take into account modern structural features:

I Not felt except by a very few under especially favorable circumstances.

II Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.

III Felt quite noticeably indoors, especially on upper floors of buildings, but many peopoe do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.

IV During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.

V Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.

VI Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.

VII Everybody runs outdoors. Damage negligible in building of good design and construction; slight to moderate in well–built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.

VIII Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motor cars disturbed.

IX Damage considerable in specially designed structures; well–designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

X Some well–built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.

XI Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII Damage total. Practically all works of construction are damaged greatly or destroyed. Waves seen on ground surface. Lines of sight and level are distorted. Objects are thrown upward into the air.

The Modified Mercalli intensity scale measures the intensity of an earthquake's effects in a given locality, and is perhaps much more meaningful tc the layman because it is based on actual observations of earthquake effects at specific places. It should be noted that because the data used for assigning intensities can be obtained only from direct firsthand reports, considerable – time weeks or months – is sometimes needed before an intensity map can be assembled for a particular earthquake. On the Modified Mercalli intensity scale, values range from I to XII. The most commonly used adaptation covers the range of intensity from the conditions of "I–not felt except by very few, favorably situated," to "XII–damage total, lines of sight disturbed, objects thrown into the air." While an earthquake has only one magnitude, it can have many intensities, which decrease with distance from the epicenter.

COMPARISON OF MAGNITUDE AND INTENSITY

It is difficult to compare magnitude and intensity because intensity is linked with the particular ground and structural conditions of a given area, as well as distance from the earthquake epicenter, while magnitude depends on the energy released at the focus of the earthquake.

Richter Magnitude	Expected Modified Mercalli Maximum Intensity (at epicenter)	
2	I–II	Usually detected only by instruments
3	III	Felt indoors
4	IV–V	Felt by most people; slight damage
5	VI–VII	Felt by all; many frightened and run outdoors; damage minor to moderate
6	VII–VIII	Everybody runs outdoors; damage moderate to major
7	IX–X	Major damage
8+	X–XII	Total and major damages

After Charles F. Richter, 1958, *Elementary Seismology.*

APPENDIX C

SURVEY FORM DISTRIBUTED
TO INSURANCE INDUSTRY OFFICIALS

INSURANCE INDUSTRY QUESTIONS
MANAGING THE INEVITABLE CONFERENCE
MAY 14-17, 1989

Insurance Business

1. Do you sell property and casualty insurance in California?

2. Do you sell earthquake insurance in California? Throughout the State?

3. Roughly, what proportion of your property/casualty insurance premiums are from earthquake insurance?

4. If so, do you sell commercial lines? Earthquake insurance for dwellings?

5. Roughly, what percentage of your earthquake insurance business is for commercial lines? Residential lines?

6. Roughly, what percentage of your company's commercial line sales of earthquake insurance are reinsured? What percentage of the residential lines are reinsured?

7. If so, would you continue to sell earthquake insurance for dwellings in California if there was no legal requirement to do so?

8. If you sell earthquake insurance in California, do you aggressively market the sale of such insurance? Why or why not?

9. Does your company plan to or anticipate increasing the earthquake insurance portfolio?

10. Will the recent California Supreme Court decision regarding Proposition 103 have any effect on your offering earthquake insurance? Will your company be more aggressive or less aggressive in marketing earthquake insurance in California?

Risk Estimation

11. What method do you currently use to estimate earthquake risk?
    Probable maximum loss estimates
    Insurance Services Office Guidelines?
    Expert System?
        IRAS at Stanford?
        National Technical Systems?
    Other?

12. Do you evaluate the earthquake risk of potential customers before issuing earthquake insurance policies?

13. Does your loss estimation methodology use specific earth science information (soil types, groundwater tables, slope) to generate estimates of ground shaking, liquefaction, ground failure, and landslides?

14. Is this data used directly in estimating losses? If not, how is it used? (To manage the company's exposure, ratesetting, or other.)

15. What is the source of the earth science data included in your methodology?
    USGS?
    CDMG?
    Private sources?

16. Would additional or improved earth science information be useful in estimating earthquake risk?

17. What type of information would be most useful?
    Ground shaking?
    Fault rupture?
    Ground failure?
    Liquefaction?
    Landslide potential?

18. What type of information would **not** be useful in estimating risk?
    Ground shaking?
    Fault rupture?
    Ground failure?
    Liquefaction?
    Landslide potential?

19. At what level of detail or scale would this information be most useful?
    Regional or county level?
    Postal code level?
    Census tracts?
    Other?

20. What format for this information would be most useful? Data identified by
    Regional or county level?
    Postal code level?
    Census tracts?
    Other?

21. In your opinion, who should provide this information?
    Federal government (USGS)?
    State government (CDMG)?
    Private organizations?

22. Would your company be prepared to pay for this information?

Ratesetting

23. Are your earthquake insurance rates and deductibles based on loss estimation activities undertaken by your company?

24. What is your company's primary objective in setting insurance rates? To manage annual losses or provide coverage for catastrophic losses?

25. How are deductibles used? To minimize small but frequent losses or to provide protection against catastrophic losses?

26. If better earth science information were made available, would it be helpful in setting insurance rates and deductibles?

Earthquake Insurance Problems

27. In your judgment, what is the biggest problem associated with earthquake insurance? (Adverse selection, lack of information, uncertainty, government regulation, or other.) Why?

28. What can government (federal and state) do to alleviate this problem?

29. What can the insurance industry do?

###

APPENDIX D

SURVEY FORM USED IN INTERVIEWS WITH LOCAL GOVERNMENT OFFICIALS

URBAN SEISMIC HAZARD MAPPING PROGRAM SURVEY: USE OF SEISMIC HAZARD INFORMATION BY LOCAL PLANNING AND BUILDING DEPARTMENTS

CALIFORNIA DEPARTMENT OF CONSERVATION
DIVISION OF MINES AND GEOLOGY
630 BERCUT DRIVE
SACRAMENTO, CA 95814
(916) 322-9307

[SURVEY ID# ____]

Name: ____

Title: ____

Organization: ________________________________

Address: _____________________________________

City: __________________ State: ______ Zip: _______

Phone: _______________________

CURRENT USES OF SEISMIC HAZARD INFORMATION

1. Do you use seismic hazard information as a decisionmaking tool in the

   ___ planning process?

   ___ building department approval process?

2. Specifically, what seismic hazard information is utilized by your organization?

   ___ Alquist-Priolo Fault Zones
   ___ Landslide maps
   ___ Soils maps
   ___ Ground shaking or response zones
   ___ Liquefaction maps
   ___ Ground failure maps
   ___ Geotechnical reports prepared by consultants
   ___ Other ______________________

3. What is the source of the earth science data included in your methodology? (Please check all that apply.)

___ U.S. Geological Survey?
___ California Division of Mines and Geology?
___ Other government sources?
___ Private sources?

4. How is this information used?

___ Public information
___ Disclosure to titleholders
___ Development (or site) approval
___ To exclude certain facility or occupancy types from hazardous areas
___ Plan checking
___ Other

5. What problems, if any, are there with the current uses of seismic hazard information?

Uses of Improved or More Detailed Seismic Hazard Information

6. If improved or more detailed seismic hazard information were available to you, what type of information would be **most** useful?

___ Ground shaking susceptibility?
___ Fault rupture potential and proximity to faults?
___ Ground failure potential?
___ Liquefaction potential?
___ Landslide potential?

7. How would this information be used?

___ Public information
___ Disclosure to titleholders
___ Development (or site) approval
___ To exclude certain facility or occupancy types from hazardous areas
___ Plan checking
___ Other

8. What type of information would **not** be useful in the planning/building department function?

____ Ground shaking susceptibility?
____ Fault rupture potential and proximity to faults?
____ Ground failure potential?
____ Liquefaction potential?
____ Landslide potential?

9. How might seismic hazard information be used more effectively in the planning/building department functions?

10. What specific benefits would accrue from the use of improved seismic hazard information?

11. What adverse consequences might result?

12. What public policy implications are there on a local government level associated with the use of improved seismic hazard information by planners/building officials?

13. In your opinion, who should provide this information?

____ Federal government (USGS)?
____ State government (California Division of Mines and Geology)?
____ Local government (planning and building departments)
____ Private organizations?
____ Others? ______________________________

14. Would your organization be prepared to pay to receive this information? Approximately how much would you pay to receive this additional information?

Format for Improved Seismic Hazard Information

15. At what level of detail or scale would this information be most useful?

___ Regional or county level?
___ Postal code level (five digit zip codes)?
___ Postal carrier level (more detailed than zip code)
___ Census tracts?
___ Other?______________________

16. What map scale should the data be presented in?

___ 1:24,000
___ 1:62,500
___ 1:100,000
___ Other ________________

17. Should seismic hazards be expressed in terms of

___ Monetary losses

___ Levels based on physical parameters (e.g. shaking in terms of acceleration)

___ Relative levels of severity (high, medium, low)

___ Other ________________

18. What type of map/information would be **most** useful?

___ Maps depicting relative susceptibility of land to specific hazards, without regard to earthquake sources

___ Maps depicting relative hazards for specific earthquake scenarios

___ Maps depicting relative hazards of cumulative earthquake sources

19. Would statistical probabilities and levels of uncertainty be useful?

20. What level of uncertainty in seismic hazard information is acceptable for purposes of the planning/building department function?

- ___ 0-10 percent
- ___ 10-25 percent
- ___ 25-50 percent
- ___ greater than 50 percent

21. Seismic hazard information products would be most useful if provided in

- ___ Maps
- ___ Reports
- ___ Digital files

22. Does your organization currently use, or plan to use, geographic information system technology in planning/building department functions?

Please return completed questionnaire to:

California Division of Mines and Geology
630 Bercut Drive
Sacramento, CA 95814

APPENDIX E

SURVEY AND PERSONAL CONTACTS

Contacts/Interviews For Information Needs Assessment

Name	Position	Org Type	Org Name	Location
Doreen Liberto-Blanck	Planning Director	City Planning	Arroyo Grande Planning Department	Arroyo Grande, CA
Barry Hand	Principal Planner	City Planning	Bakersfield Planning Department	Bakersfield, CA
Glenn Johnson	Principal City Planner	City Planning	Los Angeles City Planning Department	Los Angeles, CA
Eugene Zeller	Superintendent of Building and Safety	City Planning	Long Beach City Planning Department	Long Beach, CA
Gary Bonte	Planner II	City Planning	Redwood City Planning Division	Redwood City, CA
Jim Derryberry	Deputy Director of Planning	City Planning	San Jose City Planning Department	San Jose, CA
Anne Moore	Planning Director	City Planning	San Rafael City Planning Department	San Rafael, CA
Jene McKnight	Planner	County Planning	Los Angeles County Planning Department	Los Angeles, CA
Steven Kupferman	Engineering Geologist	County Planning	Riverside County Planning Department	Riverside, CA
Paul Schowalter	Planner	County Planning	San Bernardino Land Management Dept.	San Bernardino, CA
Charles Lough	Geologist/ Environmental Planner	County Planning	San Diego Department of Planning & Land Use	San Diego, CA
A. Neuwal	County Geologist	County Planning	San Mateo County Planning Department	Redwood City, CA
Richard Roth, Jr.	Assistant Comissioner	State Insurance	California Department of Insurance	Los Angeles, CA
Karl Steinbrugge	Structural Engineer	Consultant	Private Consultant	El Cerrito, CA
Craig Taylor	Principal Investigator	Consultant	Dames and Moore	Los Angeles, CA
Risa Palm	Principal Investigator	University	Institute of Behavioral Science, University of Colorado	Boulder, CO
Weimin Dong	Acting Associate Professor	University	Stanford University Dept. of Civil Engineering	Stanford, CA
Richard Bernknopf	Economist	Federal	U.S. Geological Survey	Menlo Park, CA
S.T. Algermissen	Geophysicist	Federal	U.S. Geological Survey	Denver, CO
William Kockleman	Planner	Federal	U.S. Geological Survey	Menlo Park, CA
Don Seagraves	Executive Director	Insurance	All Industry Research Advisory Council	Oak Brook, IL

Name	Position	Org Type	Org Name	Location
Domenic Yezzi	Manager Industry Relations	Insurance	Insurance Services Office	New York, NY
Eugene Lecomte	Project Director-The Earthquake Project	Insurance	National Committee on Property Insurance	Boston, MA
Ron Wardrop	Actuarial Research Associate	Insurance	Allstate Research Planning Center	Menlo Park, CA
Paul Lenzi	Property Casualty Operations	Insurance	Continental Insurance	New York, NY
Earl Aurelius	Vice President	Insurance	EQE, Inc.	San Francisco, CA
James Smith	Vice President	Insurance	Fireman's Fund Insurance Company	Novato, CA
Karen Harshaw		Insurance	Hartford RE Management Company	Hartford, CT
Stanley Covillon	Vice President	Insurance	Industrial Risk Insurers	Hartford, CT
Lowden Jessup	Vice President	Insurance	Kemper Insurance	San Francisco, CA
Edwin A. Simner	Managing Director Merrett Group	Insurance	Lloyds of London	London, England
Ake Munkhammar	Vice President	Insurance	Skandia International Corporation	Stockholm, Sweden
Robert Odman	Assistant Vice President	Insurance	State Farm and Casualty	Bloomington, IL
Rachel Gulliver		Consultant	Gulliver Associates	Northridge, CA
Thomas Tobin	Executive Director	State	Callifornia Seismic Safety Commission	Sacramento, CA
Richard Eisner	Project Director	State	Bay Area Regional Earthquake Preparedness Project	Oakland, CA
Geoffrey Ely	Executive Director	Public	Building Manager's Association	Los Angeles, CA
Bill Regensburger		State	Southern California Earthqauake Preparedness Project	Los Angeles, CA
Ralph Maurer	Staff Risk Manager	State Office of Insurance and Risk Management	California Department of General Services	Sacramento, CA
Alvin James	Planning Director	City Planning	Oakland Planning Department	Oakland, CA

Contacts/Meetings for Assessment of Available Bore-Hole Data

Name	Position	Org Type	Org Name	Location
Richard Harding	Vice President	Consultant	Earth Sciences Associates	Palo Alto, CA
Barbara Turner	Director, I&HW Div.	Consultant	EMCON Associates	San Jose, CA
Phil Benton	President	Consultant	Benton Engineering, Inc.	San Diego, CA
Corey Dare	Senior Engineer	Consultant	Converse Consultants	San Francisco, CA
Thomas Evans	Vice President	Consultant	Converse Consultants	Pasadena, CA
Wolfgang Roth	Partner, P.E.	Consultant	Dames and Moore	Los Angeles, CA
Raymond Rice	Partner	Consultant	Dames and Moore	San Francisco, CA
Henry Taylor	Principal Engineer	Consultant	Harding Lawson Associates	San Francisco, CA
Robert Broadhurst	Senior Associate Engineer	Consultant	Herzog and Associates	Mill Valley, CA
John Rice	Senior Staff Engineer	Consultant	J.H. Kleinfelder and Associates	Pleasanton, CA
Bruce Clark	President	Consultant	Leighton and Associates	Irvine, CA
Marshall Lew	Vice President	Consultant	LeRoy Crandall and Associates	Glendale, CA
John Barneich	Senior Principal	Consultant	Woodward-Clyde Associates	Santa Ana, CA
Don Vaughn	Project Geologist	Consultant	Geotechnical Exploration, Inc.	San Diego, CA
Mike Hart	President	Consultant	Geocon , Inc.	San Diego, CA
Peter Kaldveer	President	Consultant	Kaldveer Associates	Oakland, CA
Curtis Burdette	Engineering Geologist	Consultant	Southern California Soil & Testing	San Diego, CA
William Ellis	Vice President	Consultant	Shepardson Engineering Associates	Santee, CA
Skip Pouncy	Principal Geologist	Consultant	Geo Soils, Inc.	Santa Ana, CA
Gerald Stone	President	Consultant	Eberhart & Stone, Inc.	Santa Ana, CA
Duane Lyon	President	Consultant	Richard Mills Associates	Rancho Cucamonga, CA
Stevan Pekovich	Retired	Consultant	Pacific Soils Engineering	Harbor City, CA
Frederick Zeiser	President	Consultant	Zeiser Geotechnical, Inc.	Costa Mesa, CA
Jack Eagan	Sr. Vice President	Consultant	Moore and Taber	Anaheim, CA
George Larson	Principal Geologist	Consultant	Geo Soils, Inc.	Van Nuys, CA
Jim Gibboney	Engineering Associate	State	California Department of Water Resources	Sacramento, CA
Ad Goldschmidt	Senior Engineering Geologist	State	California Department of Transportation	Sacramento, CA
Richard McJunkin	Engineering Geologist	State	California Department of Health Services	Sacramento, CA
Richard Sakaji	Senior Sanitary Engineer	State	California Department of Health Services	Berkeley, CA

Name	Position	Org Type	Org Name	Location
John Tinsley	Research Geologist	Federal	U.S. Geological Survey	Menlo Park, CA
Don Bourgeois	Materials Engineer	County	Orange County Environmental Management Agency	Santa Ana, CA
Paul Brewer	Hazardous Waste Specialist	County	Orange County Health Care Agency	Santa Ana, CA
Robert McVicker	Associate Engineer	County	Orange County Water District	Fountain Valley, CA
Bob Kroll	Principal Civil Engineering Assistant	County	Los Angeles County Department of Public Works	Alhambra, CA
George Brodt	Civil Engineer	City	Los Angeles City Department of Water and Power	Los Angeles, CA
John Peterson	Groundwater Geologist	County	San Diego County Department of Planning & Land Use	San Diego, CA
Kevin Heaton	Hydrologist	County	San Diego County Department of Health Services	San Diego, CA
Don Froelich	Senior Engineer	County	Metropolitan Water District	Los Angeles, CA
Jim Campion	Senior Oil & Gas Engineer	State Division of Oil and Gas	California Department of Conservation	Sacramento, CA
Mark McQuillkin	Supervising Engineering Geol.	State Division Dam Safety	California Department of Water Resources	Sacramento, CA
Jim Gamble	Engineering Geol.	Utility	Pacific Gas & Electric	San Francisco, CA
Don Clarke	Senior Geologist	City	Long Beach City Department of Oil Properties	Long Beach, CA
Joseph Cobarrubias	Engineering Geologist III	City	Los Angeles City Department of Building & Safety	Los Angeles, CA
Phil Daniels	Data Processing Manager	State	California Water Resources Control Board	Sacramento, CA
Richard Brewer	Associate Environmental Research Scientist	State	California Department of Food and Agriculture	Sacramento, CA
Gene Hawkins	Senior Geologist	Utility	Southern California Edison	Rosemead, CA
John Bowman	Engineering Geologist	County	San Bernardino Co.	San Bernardino, CA